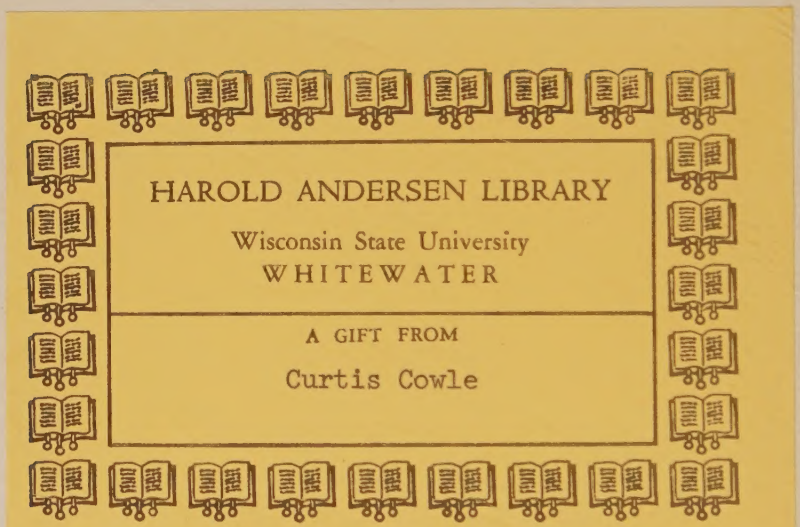
THE STORY OF STEEL

J. PETTARD WALKER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The Story of Steel

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By
J. BERNARD WALKER
Editor Emeritus of "The Scientific American"

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THE STORY OF STEEL

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Preface

In 1902 the author of the present work, accompanied by an artist and a photographer, spent several weeks among the steel works of the Pittsburgh district, and the material thus gathered was published in a special issue of *The Scientific American.* Although the chapters were written specifically for the layman, and, therefore, with as large an elimination of technical terms as was consistent with clarity and technical accuracy, they were favorably received by the schools and colleges and, in the case of one university, the issue was reprinted as a textbook for the freshmen in the School of Engineering.

Now, over twenty years later, it has seemed to the writer that since a new generation of readers has sprung up and such an enormous expansion has taken place in the steel industry, a new account is worth while. By the courtesy of Judge Elbert H. Gary the writer was enabled to make an extended tour throughout the properties of the United States Steel Corporation. This included a visit to the wonderful mines of the Missabe range, a trip with the ore by rail to the ore docks at Duluth, a journey on an ore boat down the Lakes to the Lorain works on Lake Erie, and a visit to the vast establishments at Gary, South Chicago, Cleveland, and elsewhere.

This study, enlarged by the author's constant contacts with the industry over a period of years, was the basis of fifteen articles in *The Scientific American,* which are now brought together in this book, supplemented by additional chapters dealing with some of the principal products of the industry, and its financial and marketing aspects.

It will be understood, therefore, that the present work is a broad but not exhaustive treatment of the subject. The technical chapters, although they describe more particularly the production of steel as carried on by the United States Steel Corporation, are broadly representative of the methods of manufacture employed throughout the American steel industry.

The scope of the work entailed many necessary omissions. The Lake Superior region, rich and extensive as it is, by no means covers the whole area of our resources, as witness the Birmingham region, the Colorado deposits, and the ores near St. Louis, all of which, and especially the first named, are of more or less importance. Similarly, the vast system of ore docks of the Steel Corporation at Duluth has for neighbors many other extensive docks, which receive and discharge the ore from the Lake Superior mines of other companies.

In dealing with the production and fabrication of steel, it is only limitations of space that prevent the insertion of separate chapters on cold-rolled strips, merchant bars, forgings, stampings, deep-drawn work, cast-

ings, or on the fascinating subject of tool steel, in the development and production of which such great advance has been made of late years.

Notwithstanding these necessary omissions, the author trusts that he has accomplished his object of presenting, in compact form, a survey of the practice of steel-making, which will enable the layman and the technical student to get a firm grasp upon the outstanding principles and practice of an industrial art, to which, more than to any other, is to be credited the present amazing wealth and prosperity of the United States.

In order to round out the work, chapters have been added on the United States Steel Corporation Financial Policy; one on Marketing the Finished Product, which deals with the selling methods of the United States Steel Corporation; and two chapters on the general aspects of marketing and financing throughout the industry by Mr. Edmund Brown, Jr., member Consulting Board, Brookmire Economic Service, Inc.

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The Story of Steel

The Story of Steel

CHAPTER I

The Amazing Growth of Steel in Two Decades

The story of steel is the story of the astonishing industrial development of the United States during the past quarter of a century. The secret of that development is to be found in the opening up of the enormous deposits of ore in the Missabe range to the north of Lake Superior, and the characteristic American operations on the grand scale in mining, transportation, smelting, and fabricating into steel, by which the contents of that treasure house of Nature's providing have been transformed into ten thousand commodities to meet a world-wide demand.

The magnitude of the steel industry expressed in numerical statistics makes only a vague impression on the mind; these figures have to be reduced to some concrete form if any adequate conception is to be conveyed. Thus, the statement that the United States, in the year 1918, mined over sixty-nine million long tons of ore fails to convey an adequate impression of the vastness of this total; but if we should see the entire ore production for that year piled up in a single

heap, we would get an instant comprehension of its meaning by comparing it with familiar objects in the landscape. The mind is confused by large numbers, but it grasps quickly the sight of large concrete quantities. The statement that a wagon holds 30,000,000 grains of coal would give a person a very hazy idea of the actual quantity specified; but he would comprehend the quantity at once if he were told that it represented two tons. The larger unit of weight would reduce the count to a figure readily within his mental grasp.

In comparing the statistics of the industry in the twenty years, 1902-1922, we wish to make it clear that we have chosen for comparison the year in which the quantities of ore, coke, pig and steel, etc., reached their highest figure. This occurred in 1918, that year of feverish industrial activity. The working forces and general equipment which handled and produced the enormous quantities of 1918 are available, probably in even greater measure, today. Hence, the output of 1918 may be very fairly taken as the measure of our maximum capacity in 1925.

Coke

Now we find that in 1902, the amount of coke used in the furnaces of the United States was 16,000,000 tons. Coke is so light in weight that, if the 16,000,000 tons were built up in a column 400 feet square on the base, it would reach an altitude of 6,500 feet.

No work built by human hand has ever been erected that would give us, by comparison with this column, any idea of its magnitude; for if the base of the column were situated at sea level, a person at the top would look down on the summit of Mt. Washington, New Hampshire, and he would find that it overtopped every mountain in this country east of the lofty range of the Rocky Mountains. Sixteen years later, the coke used in our furnaces had reached 45,703,594 tons.

Limestone

The limestone used for fluxing purposes in the blast furnaces amounted in 1902 to 9,490,090 tons, which would be represented by a column 5,500 feet high on a base 200 feet square. In the year of maximum production, there was consumed a total of 19,208,403 tons of limestone. The purpose of the limestone is to form a flux with the impurities in the blast

Growth of Steel Industry in Two Decades

	1902	1922	1918
Ore mined in United States	34,636,121	47,128,572	69,658,278
Coke used in furnaces	16,000,000	29,213,893	45,703,594
Limestone	9,490,090	11,719,638	19,208,403
Pig iron	17,821,307	27,219,904	39,054,644
Rails	2,947,933	2,171,776	2,540,892
Plates and sheets	2,655,409	7,968,397	8,799,135
Wire nails, 100-lb. kegs	10,982,246	15,053,330	12,279,800
Cut nails, 100-lb. kegs	1,633,762	810,206	418,811
Structural shapes	1,300,326	2,718,768	2,849,969
Steel ingots and castings	14,947,250	35,602,926	44,462,432

furnace charge, which, being lighter than the molten pig iron floats on the surface of the iron and may be tapped off separately. Twenty years ago slag thus formed was more or less of a nuisance, and was hauled away to be dumped as one of the wastes of steel-making. Increasingly, during the past two decades, slag has come to be recognized as useful material for the ballasting of railroad tracks, the building of roads and more lately and above all as a valuable constituent in the manufacturing of cement—an industry which has grown to vast proportions in this country, and is rapidly supplementing, if not supplanting, steel, in many buildings and bridges.

Iron Ore

The iron ore mined in 1902, amounted to 34,636,-121 tons. This amount, if it could be piled up into a square column, because of the greater weight of the material would represent a much smaller mass than the 16,000,000 tons of coke. If it were built up on a base measuring 200 feet square, it would reach to a height of 6,500 feet. The largest output of iron ore occurred in 1918, when there was mined 69,658,278 tons, of which, by the way, 40,396,711 tons came from the great Missabe range.

Pig Iron

All the great mass of materials above referred to was consumed in producing respectively 17,821,-

307 tons of pig iron in 1902, and 39,054,644 tons of pig iron in 1918. Due to the industrial depression, from which there has been a gradual recovery, the total output of pig iron in 1922 was only 27,219,904 tons.

Steel Ingots and Castings

In the earlier years of the industry, the bulk of the molten iron, as it was run from the smelting furnaces, was cast into pig; but with the development of modern methods, the preliminary casting into pig has been practically abandoned in favor of transferring the molten iron directly to the mixing machines and the Bessemer converters and open-hearth furnaces for conversion into steel. The total output of steel ingots and castings in 1902 was 14,947,250 tons. Of this total 9,138,363 tons was converted from "pig" into steel by the Bessemer process, and the balance by the open-hearth process. In 1918, the output was 44,462,432 tons. During the past twenty years, the proportion of open-hearth to Bessemer steel has been steadily increasing, so that in 1922 only 9,376,236 tons out of the total output of the blast furnaces was converted by the Bessemer process.

Steel Rails

It is a curious fact that, in spite of the great increase in production of the various finished steel products, the

output of steel rails in 1924 was actually less than that of 1902; the respective totals being 2,947,933 tons in 1902 and 2,433,332 tons in 1924. The explanation of this decline is to be found in the fact that, twenty-four years ago, we were still in the midst of an era of great expansion of our railroad system, the total amount of new lines constructed in 1902 being 5,076 miles. Shortly thereafter, as the needs of the country were supplied, there commenced a falling off in new construction; so that today the total of new work is limited. That the output of rails is as high as it is may be set down to the fact that the rail renewals on our 260,000 miles of track assist in keeping our rail mills fairly well occupied. The rail production of 1902, if formed into a single rail of standard proportions, would be 81 feet high with the same width on the base, and the head of the rail would have a width of 43 feet. A rail built on these proportions would extend for one and one-fifth miles before the year's total tonnage of rail had been included.

Plates and Sheets

The finished product in the steel industry which bulks the largest is that of plates and sheets, the output of which had grown in sixteen years from 2,655,409 tons in 1902 to a maximum output of 8,799,135 tons in 1918. Even this last figure was exceeded in 1920 when the output was 9,337,680 tons.

Furnace Capacity

The furnace output in 1918 was more than double what it was in 1902; and this brings out the interesting fact that the total number of furnaces has shown only a moderate increase of from 406 in 1902 to 459 in 1918, and this in spite of the fact that in the interval the total output of pig had increased over 100 per cent. This is explained by the fact that the average furnace of today is far larger and more efficient than it was twenty years ago.

CHAPTER II

Missabe, the Greatest Iron Mines in the World

Now and again something happens in one's lifetime which stands out in the long perspective of the past like some isolated hill in a landscape. Among such memories will ever remain the writer's first sight of the largest of the open-pit mines of the Missabe range, to the north of the city of Duluth. It was in the early hours of a frosty October morning, after a drive through the mining town of Hibbing, that he dismounted near a small wood, passed through it and found himself on the edge of the greatest artificial hole ever dug by man in all the long ages of his history. Between 300 and 400 feet deep was that vast canyon, and from its lowest level it sloped irregularly on either side up to the original surface of the ground, leaving a gap three-quarters of a mile in sheer stretch from edge to edge. For a full two and a quarter miles the awe-inspiring chasm yawned ahead, its further limits barely discernible in the morning haze.

The writer is not devoid of imagination, and he had heard of the Gargantuan proportions of the Hull Rust Mine; he had looked down into the great Culebra Cut at Panama; but for all that he could not repress, if he had wished to, a gasp of astonishment. Here was some-

HULL RUST IRON MINE AND CULEBRA CUT, PANAMA, COMPARED ON THE SAME SCALE AT THE POINT OF THEIR DEEPEST AND WIDEST EXCAVATION

thing which, as a feat of excavation, rendered even the Panama Excavation at its widest point, modest by comparison. Culebra's largest cross-section is found where the big slides have opened out the excavation to a width of 1800 feet on a certain-line depth of 240 feet; but at Hull Rust the steam shovel and the ore train had dug and dug and carried away, until we have today a hole 320 feet deep at its lowest point, and extending to a width of 4000 feet at its widest part.

But where are Hibbing and Hull Rust, and why this enormous excavation which, be it known, is only one of over a hundred mines scattered along the great Missabe iron range, which extends east and west for 112 miles? To answer that question, we invite the reader to go by rail and Lake steamer to the city of Duluth, which is built upon the steeply sloping bluffs that rise from the northerly shore of the lake. These bluffs reach a rather uniform height of 600 feet; and when the train, climbing on a 2-per-cent grade reaches the top of the bluffs, the traveler finds himself on a great plateau which extends, practically level, to the Canadian boundary. Eighty miles inland from Duluth he will reach Hibbing, which is located at about the center of that vast stretch of iron-ore deposits known as the Missabe range. Fifty years ago this plain was given over to forest growth, and the occasional hunter who walked its solitary trails, little imagined that under his feet and not so very far down, was one of the greatest of the treasure houses of wealth which nature had

locked up in far-distant ages for the future enrichment of mankind.

Iron must be placed at the top of the list of metals which have been found in this world; for it exists in greater quantity, and has been put to more widely extended use than any other. You may find it in some measure in practically all of the rocks and earths, and we know how frequently a stream of water, or even the water from a well, will show the characteristic reddish deposit which indicates the presence of iron. The geologist will tell you that millions of years ago great volumes of water, pouring through underground channels, washed out of the various rocks and soils of the earth this rich deposit, and by chemical action changed it into the characteristic red and yellow iron ore, which found a settling basin in the many hollow depressions which characterize the Missabe range.

Only a part of the world's iron deposits can be made into steel; for much of it is so mixed with other substances as to make it very expensive to melt down into iron by any method that man has so far been able to devise. Naturally, the ores which are most cheaply reduced to iron are those which have been most sought after and mined, and the greatest deposits in the world of this character are those to be found in the vicinity of Lake Superior. Not only are these the largest, but they are richer in iron and less burdened with those more or less troublesome elements which always are found with iron ore, such as phosphorus, silicon, sul-

phur, aluminum, etc. Iron ore is valued mainly on the basis of the amount of iron it contains, and also upon the amount of the undesirable elements that it contains and the cost of getting rid of them in the blast furnace.

Now, although iron ore has been mined in the Lake Superior region from the middle of the last century

STEAM SHOVELS DIGGING OUT THE RICH ORE IN THE HULL RUST OPEN-PIT MINE AND LOADING IT INTO STEEL RAILROAD CARS

onward, it is only of late years that the total output has risen to such great proportions as to give this country its commanding lead in the steel industry of the world; and among all the Lake Superior ranges the one which has contributed most to the growth of our steel industry has been the famous Missabe range, which as we have said, extends in an easterly and westerly direction for no less than 112 miles. Not only

are these deposits of enormous size, but nature has so placed them that it is possible to dig them out and remove them at a cost per ton far below that which is possible in any of the mining centers of the world. The ore bodies of the Missabe, as they were deposited ages ago, exist in more or less continuous beds, which vary in width from a few hundred to thousands of feet, and in the Hull Rust and Mahoning Mines, extend without a break for between four and five miles. These ore bodies vary in thickness from a few feet to over 300 feet and from a few acres to several hundred acres in extent. After their formation, the great ice cap came crushing and grinding its way down from the north, bringing with it a vast amount of sand, gravel and boulders with which it covered up the ore to an average depth of about 70 feet. There it lay, a vast storehouse of wealth, locked up securely until the day when man should make his appearance upon the earth, and develop to the point where he had the intelligence and the appliances to transmute this raw material of nature into the thousand-and-one steel products demanded by our highly developed civilization.

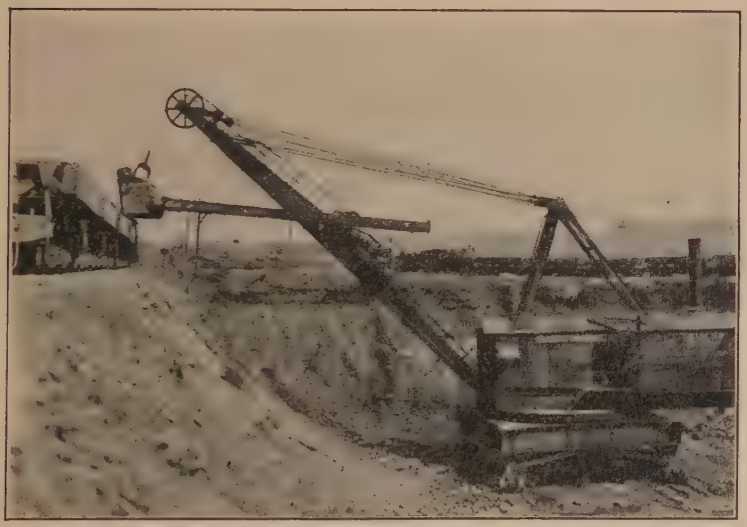
The first mining of iron ore in Minnesota was done with very primitive tools, such as could be packed from Duluth over a hundred miles of forest to the first mines on the Vermilion range. In the early 'eighties work was done with pick and shovel, hand drill and wheelbarrow; shafts were sunk and the ore was hoisted in buckets by a horse-operated winch and carted from

the mouth of the pit in horse-drawn wagons. Then, with the railroad, came the steam engine, and a few years later the hand drill gave place to the air drill. Later, in the 'nineties, came the car cage with its landing gates, the stockpile trestle, electric lighting, Corliss hoisting engines and an increase in the capacity of the railroad ore car to 25 tons.

Also in the early 'nineties, following the methods of the day in deep mining, the miners of the Missabe sank shafts through the overlying glacial drift to the ore body below; but when it was found that the ore lay very close to the surface, the momentous decision was taken to strip off this over-burden and take out the ore by scrapers and horse-drawn wagons. Finally came another momentous advance in the introduction of the steam shovel; and as an inevitable sequence to this came the determination to run the railroad cars themselves down into the open pit and load them directly from the shovel itself.

The system of open-pit mining having thus been started, the problem became merely one of applying the American principle of working with the largest units of machinery that could be built and operated. There was a steady growth in the size from the 35-ton pioneer shovel, until the Oliver Iron Mining Company placed in the Hull Rust Mine the enormous Marion machine shown in one of our engravings. This shovel weighs 300 tons and its dipper lifting 16 cubic feet of ore at one scoop, has 16 times the capacity of the dipper of the

early shovels. The early dump cars were of wood and each carried one cubic yard. The present cars are built entirely of steel, and each has a 30-cubic yard capacity. In place of the little six-ton "dinky" steam locomotive, we have the huge modern locomotives with 100 tons of weight on the drivers, which handle the



THIS 300-TON SHOVEL MAKES A CUT 40 FEET DEEP AND 175 FEET WIDE THROUGH THE BED OF IRON ORE, ITS DIPPER LIFTING 16 CUBIC YARDS AT EACH STROKE

cars in the pit and haul them up the long steep grades to the main tracks above, where they are assembled in trains of 80 to 100 cars for transportation to the ore docks at Duluth.

In opening up a mine on the Missabe range, thorough exploration is first made by means of diamond or churn drills, and the depth of the glacial deposit and of the

ore body below is closely determined. If the cost of stripping and mining by open-pit, steam-shovel methods is found to be less than that of deep mining by shafts and tunnels, the open mining method is followed, as at Hull Rust. The operations involved in stripping off and removing the glacial drift are on an enormous scale, for they involve the removal of millions of tons of material to dumps that are located sometimes at considerable distances. Obviously, the material must be deposited on lands which have no available ore below them. The spoil is deposited in dumps of Cyclopean proportions which extend for thousands of yards and reach pretty nigh to a hundred feet in maximum height. These accumulations are as wonderful, in their way, as the huge excavations from which the material is taken. When the ore body has been exposed, the steam shovels cut their way into it, the depth of the cut being governed by the height to which they can raise the ore and drop it into the cars.

In 1920, at the annual meeting of the American Institute of Mining and Metallurgical Engineers at Duluth, it was stated that, since the Missabe range was opened there had been removed 354,301,371 cubic yards of stripping. Compare this with the total excavation of about 240,000,000 yards at Panama. The total stripping and lean ore together would make 363 city blocks, each 300 feet in height. There is a total known ore reserve at Missabe of 1,400,000,000 tons.

The combination of steam shovels of great capacity,

large cars, and powerful engines accomplishes a great saving in labor, and the output per man per day from an open-pit mine is many times that from the average underground mine. In this respect, the key to the situation is the giant steam shovel, whose huge dipper tears from the side of the cut a mass of ore weighing 20 tons and drops it into the cars at a height of 50 feet above the rails on which the steam shovel stands. The steel boom, which weighs just under 50 tons, is 85 feet in length, and the dipper stick, some 50 feet in length, weighs 18 tons. These figures explain the great horizontal and vertical reach of the machine, which makes a cut 40 feet deep and 175 feet in width. Twenty tons a minute means well over a thousand tons an hour, and the tracks are so laid and the trains so manipulated that the work of the shovels goes on, except for repairs, uninterruptedly night and day for eight months of the year.

With these figures in mind, we are prepared to learn that the Hull Rust Mine alone, during the great activity of 1916, shipped out 7,665,611 tons of ore, or over 10 per cent of the total of 75,167,672 tons mined in the United States. The magnitude of the Missabe range mines, in comparison with the others in the Lake Superior district, is shown in the following record of output for the busy year of 1918, when the total output from Lake Superior was 62,836,172 tons. The shipments were: Vermilion, 1,192,908 tons; Cuyuna, 2,478,800;

Marquette, 4,354,297; Menominee, 6,378,698; Gogebic, 7,936,701, and Missabe, 40,396,711 tons.

An estimate several years ago by the United States Government of our national wealth placed it at 220 billions of dollars; it may well be 350 billions today. If the writer were asked to name the principal agent in the enormous growth in wealth of this country during the past two decades he would unhesitatingly name the vast iron deposits of the Lake Superior region and the consequent phenomenal growth of our steel industry.

CHAPTER III

From Mine to Rolling Mill

Were it not for the existence of the Great Lakes, the vast mines of the Missabe would be an asset of questionable value. To produce steel cheaply you must have abundant supplies of three things—iron ore, coal, and limestone. Moreover, they must be available in enormous quantities and located reasonably near to one another. It is for this reason that steel works, the world over, are to be found in the vicinity of coal and iron ore; or are so located, that the raw materials can be brought to them at a reasonable cost of transportation.

Now the Lake Superior iron mines are grouped around the westerly end of Lake Superior, and at a distance of from 800 to 1,000 miles from the coal fields. If the iron ore had to be hauled that distance by rail, the cost would be prohibitive. Fortunately, when nature, ages ago, prepared the ore beds of the Missabe range, she grouped them within easy reach of that magnificent body of fresh water known as the Great Lakes. It merely remained for man to develop the proper methods of handling and the right kind of ship, to bring these vast deposits cheaply to the storage yards of the blast furnaces. The present chapter in the story

of steel shows how cleverly and on what a vast scale this has been done.

The largest tonnage of ore moved over the Great Lakes in a single season was during 1916, when 64,734,198 gross tons were carried through the Lakes. For a comparison of the cost of moving this tonnage, let us take the year before the war, 1913, and let us

IN THIS GREAT YARD, 2½ MILES IN LENGTH, ARE 96 PARALLEL TRACKS. HERE THE ORE CARS ARE REASSEMBLED, ACCORDING TO THE CHARACTER OF THE ORE, FOR SHIPMENT TO THE DULUTH ORE DOCKS. THIS YARD HAS HANDLED 22,000,000 TONS IN A SINGLE SEASON

consider the Lake Shore Railroad which, because of its easy grades and fine roadbed, is ideal for cheap transportation. In that year the freight rate was 5.29 mills per ton-mile. In the same year the freight rate per ton-mile on the Great Lakes was 0.68 of a mill. Of course, the charges both for steamer and rail have gone up; but they have advanced proportionately and the relative cheapness, as between steamer and rail, holds good today. These figures show what an abso-

lutely necessary link in the vast steel industry of the United States is that thousand-mile stretch of water between Duluth and the steel works and the ore-carrying railroads on the southern shores of Lake Michigan and Lake Erie.

In the previous chapter we showed how, by the combined use of the steam shovel and the ore train, there was shipped out of the Hull Rust Mine alone, in 1916, a total of 7,665,611 tons of ore, and that the total output from all the mines of Lake Superior was 62,836,172 tons. It is the purpose of the present chapter to show how this vast tonnage is brought down from the mines to the ore docks, transferred without delay to a great fleet of ore steamers, carried through the Lakes, and unloaded at or near the various steel works on the lower Lakes.

At the Hull Rust Mine, which is the property of the United States Steel Corporation, the ore cars, after they are hauled up out of the pit, are made up into trains which average 96 cars, or 4,800 tons of ore, per train. As soon as a train is complete, it is dispatched over the magnificent roadbed of the Duluth, Missabe, and Southern Railway Company for the run to the docks at Duluth. Although this is a freight railroad, it is built with 100-pound steel and, in part, with steel ties, and it is maintained in as fine condition as any main trunk line track running out of New York. Here again, nature has favored the steel industry, for the first 70 miles or so of the trip is across a practically level country. The

speed of the ore trains is from 25 to 30 miles an hour. They are dispatched at the rate of 30 trains per day, although the writer was told by Mr. W. H. Hoyt, chief engineer of the road, that on some days as high as 36 trains have hauled a total of 173,000 tons of ore per day from the mines to the classification yard at Proctor.

It should be explained that the cars of ore are sampled at the mines as soon as they are loaded. The samples go to a chemical laboratory and the distribution of the cars is telephoned from the laboratory to the main scale office at the Proctor yard, near Duluth, before the train reaches that point. As the trains enter the yard, the cars pass over weighing scales at a speed of two miles per hour. The scales operate automatically, the weighing device itself stamping the gross weight of the car on a card as it passes over the scales. At Proctor the trains are broken up by sorting engines, and the ore from different mines is placed together in train loads, so that when the ore is being shipped through the ore pockets and into the boats, certain definite mixtures of ore are built up, carrying the percentages of iron, silicon, phosphorus, and sulphur required at the particular furnaces where the ore is to be smelted. To handle this enormous tonnage, the Proctor yard has been built with 96 parallel switching tracks. It is 550 feet wide, in part, and 2½ miles in length. We present a view showing only a small section of the yard, with 14 trains standing side by side. The mixing of the ore above referred to is revealed in this picture by the differ-

ence in the shade and in the fragmentation of the ore. From the yard the ore is taken down to the docks over six miles of 2-per-cent grade, by large Mallet engines with 415,200 pounds weight on the drivers.

Nowhere in all America has the problem of handling and transferring a huge tonnage, in a minimum of time and at a minimum of cost, been worked out to such perfection as is seen in the transportation of ore from Missabe to the far distant steel works. Thus, the unloading from car to ship is done entirely by gravity. To this end a series of huge ore docks provided with pockets has been built along the foreshore at Duluth. We show a view of three docks of the Duluth, Missabe and Northern Railway, with the city of Duluth in the distance. Each dock is 2,004 feet in length and the largest is 84 feet 5 inches in height from the water to the deck of the dock, and 60 feet in width. When the ore trains reach the bottom of the hill, they are moved out on to the ore dock, and their contents dumped into the ore pockets. There are on one single dock 384 pockets with a total storage capacity of 153,600 tons. The dock is built of steel and concrete, and the bottom of the pockets is 40½ feet above the water. At this level each pocket is provided with a massive hinged spout which is raised and lowered by an electric winch on the floor of the dock. The pockets are spaced twelve feet from center to center, so that when loading is going on the spouts will register with the hatches on

the ore ship, which are also spaced on twelve-foot centers.

An entertaining chapter might be written upon the development of the ore-carrying craft of the Great Lakes. We must content ourselves here with stating that the first shipment of iron ore took place in 1853,

THREE OF THE ORE DOCKS AT DULUTH. LENGTH 2004 FEET; HEIGHT 84½ FEET; WIDTH 60 FEET. COMBINED CAPACITY OF ORE POCKETS, 345,000 TONS

when 152 tons were shipped from the Cleveland Iron Mining Company to the Sharon Iron Company, Sharon, Pa. Lake transportation was done in those days in little vessels of twenty tons burden or less. As the years passed the shipments and the vessels that carried them grew in size—slowly at first and then with increasing rapidity—until today the typical ore ship is a vessel over 600 feet in length, 60 feet in beam,

and capable of carrying from 10,000 to 14,000 tons of ore. These vessels have been developed purely along utilitarian lines. With their long, narrow, shoal bodies, broken by deckhouses only at bow and stern, they have none of the beauty of sheer and sweetly moulded lines which are found in an ocean-going liner. But for their particular work of carrying a huge cargo at a fair speed, and of being loaded and unloaded rapidly, they are a positive triumph of human design. In a test of the steamship *D. G. Kerr,* to see just what could be done in the way of quick loading, 12,817 gross tons of ore were unloaded from the ore pockets to the hull in 16½ minutes at the D. M. and N. docks, and as a record of quick unloading at the steel works we may note that eight Hulett unloaders at the Ashtabula pockets have unloaded 70,000 tons from seven ore boats in 22 hours, actual time, and 13,000 tons have been unloaded from a single boat in 3½ hours.

The writer, on reaching Duluth from the Hull Rust Mine, arranged to make the trip through the Lakes on a typical ore steamer, the *Thomas F. Cole* (Captain W. E. Stover), one of the fleet of 99 ore boats of the United States Steel Corporation. While the *Cole* was still warping alongside the ore dock, the spouts of alternate coal pockets dropped down above the respective hatches of the ship, and as soon as the ship stopped, the gates of the pockets were tripped, and 17 cataracts of ore began to stream down into the hull. Meanwhile, two big streams of water ballast from 14-

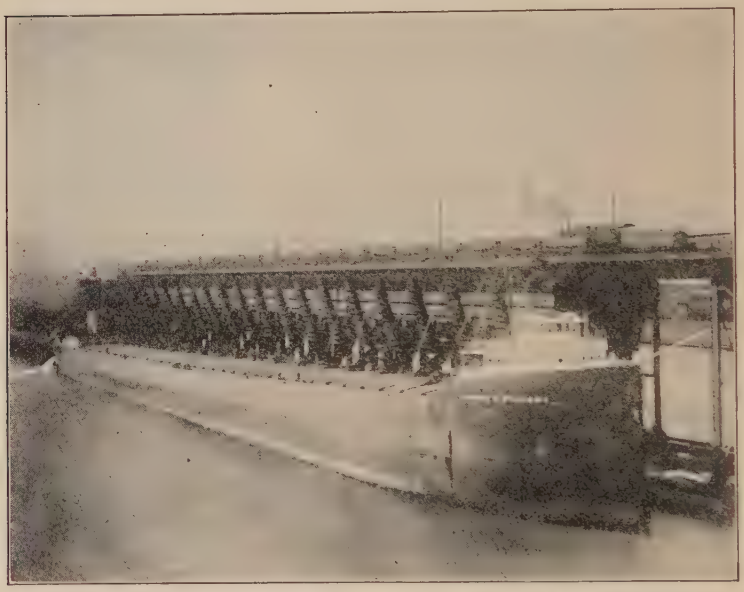
inch and 9-inch pumps were being discharged from the ship's side tanks. Care has to be taken to load a ship evenly and avoid any concentrated bending stresses. By means of wire cables and powerful winches on board, the *Cole* was moved along the dock so as to receive the proper grades of ore to make up the right mixture for the Lorain Steel Works, to which she was bound. In 2½ hours' time about 12,000 tons of ore had been taken aboard, the hatches closed and the mooring cables cast off. It was a novel experience to stand on one side of the deck and line up the opposite rail against some mark on the dock, and note how rapidly the ship sank in the water. Such rapidity of loading is not approached anywhere in the world.

We have said that the Great Lakes ore boat is a very special type. It looks different from any other and its internal construction is decidedly different. Strictly speaking, these vessels might be called magnified canal boats, with the pilot house and captain's and crew's quarters occupying the first hundred feet from the bow, and the bunkers, engine room and engine room crew accommodations filling up the last hundred feet at the stern. The remaining 400 feet of such a ship as the *Cole* is given up to the carrying of ore, or on the return voyage, of a cargo of coal. A midship cross section shows two wide water ballast tanks, one on each side, extending throughout the ship, and a series of 34 deep and stiff girders reaching from side to side to hold the hull to shape and carry the hatch covers. Return-

ing light, the *Cole* will carry normally in the tanks from 4,000 to 6,000 tons of water ballast. She is driven by triple-expansion engines, steam being supplied by two Scotch boilers at a pressure 170 pounds per square inch. With a horsepower of 2,150 and 84 revolutions per minute, she makes about 11.4 knots loaded. Her average load last year for ten trips was 12,189 tons of ore. The consumption of coal per day is only 48 tons. A truly remarkable performance considering the load and the speed.

The writer has voyaged in his time on all the seven seas, and in every size of craft from a 150-ton coasting schooner to the *Leviathan* of 64,100 tons displacement, and he thought that he knew something about navigation and the ways of ships and the sea; but that trip down the Great Lakes was a revelation. Not merely the ships, but the way in which they are sailed afford a positively novel experience. In the first place, one is practically never out of the sight of other boats. Ahead and astern will be several ore boats going the same way, and generally at about the same speed; and in the narrow waterways, the returning empties stream by one, almost like taxicabs down Broadway, New York. This is an exaggeration of course; but the reader will understand what is meant when he is told that after leaving the "Soo" locks, we met and passed in the channel no less than 24 big cargo boats, most of them of 10,000 tons or more, in a distance of twelve miles. Moreover, at this point the channel was sometimes only some 300

feet in width. Such congestion would call for most careful navigation even in clear daylight weather; but that particular twelve miles was navigated in the late afternoon, and when the dusk of twilight was deepened by the prevalence of heavy smoke from the autumn for-



A 14,000-TON ORE SHIP ALONGSIDE ORE DOCK. ORE FED BY GRAVITY THROUGH CHUTES FROM THE DOCK HOPPERS TO HOLD OF SHIP. IN A TRIAL TEST FOR MAXIMUM SPEED 12,817 TONS WERE SHOT ABOARD IN 16½ MINUTES

est fires. Not soon will the writer forget the eight hours from late afternoon to after midnight, that he spent in the pilot house. At the open window, glass in hand, stood the captain, watching for those two white lights at the masthead of approaching ships to show up through the murk, and sounding at intervals the three warning

blasts that are characteristic of Lake navigation. Presently out of the blackness would be seen the lofty masthead lights and then the red and green lights, of an approaching freighter. Speak of sea room! To our unpracticed eye it looked as though collision was surely inevitable. Then, and not so many hundred yards distant, the green light would be shut out. Presently, there would loom up the black, high bow of an empty ore boat, and she would sweep by so closely that one literally could have tossed a biscuit aboard. Vastly different this from the transatlantic ship which, as soon as she has dropped the Sandy Hook pilot, travels on a clearly defined easterly course, and knows that the westbound ships are on their own course a hundred miles or so to the north.

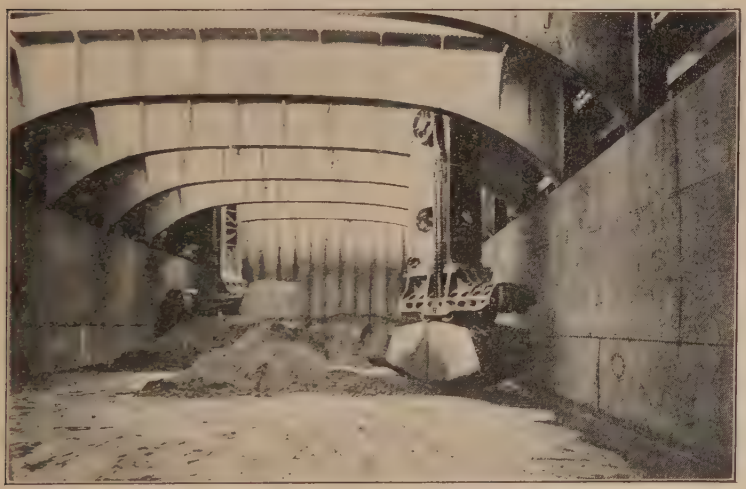
The open season for getting down the huge tonnage of ore on Lake Superior is only eight months in length. Hence, all possible speed is made in the turn-around at terminals and during the passage. When the captain takes his ship out for its first trip in the middle of April, he knows that he is in effect setting out on a voyage of 40,000 miles, which lasts from the middle of April to the middle of December. There is practically no shore leave for him and his crew. Before he has completed tying up at the ore docks the ore is pouring into his ship. Scarcely has he completed tying up at the steel works, before the unloaders are diving into his hold to bring the ore out. It is a strenuous life, and the three months of rest during the winter are well earned

by captain, crew, and ship. Each vessel, it need scarcely be said, undergoes during the winter a very thorough overhaul, and it has to be put into absolutely first-class condition. The few hours' stay in port affords the engineer no opportunity to lift cylinder covers or make any major repairs. As we have said, it is practically a continuous 40,000-mile voyage of eight months.

That excellent body of trained engineers known as the Corps of Engineers, United States Army, have had their share in building up this wonderful system of Lake transportation. Their most notable work, outside of the provision of lighthouses and the dredging of harbors, has been done at and around the rapids of St. Mary's River, where they have dredged and blasted some 45 miles of canal, with a least width of 300 feet and a minimum depth at low stage of 21 feet. Other notable work has been the construction of a series of locks, two of which are the longest in existence. These include the Weitzel Lock—515 feet by 80 feet; the Poe Lock—800 feet by 100 feet; the third lock 1,350 feet by 80 feet, and the fourth lock of the same dimensions. The various channels approaching the locks, through St. Mary's River and elsewhere, are excellently lighted, and the captains of the ships, through long familiarity, navigate these channels, even in very foggy weather, with an accuracy and an absence from grounding or collision that is positively uncanny.

We reached the easterly end of Lake Superior at

night, and in thick weather, and therefore anchored outside the canal. During the night the stream of traffic coming up behind us halted also, and when day broke and the fog lifted there were some eight or ten big freighters, fully loaded, bunched around us. We tied up alongside the pier awhile, until two big 12,000-



TAKING OUT THE LAST OF THE ORE FROM THE HOLD. NOTE THE MASSIVE LEG AND BUCKET OF HULETT UNLOADER, WHICH CAN PICK UP 17 TONS AT A SINGLE GRAB

ton ore boats which were in the lock had steamed out. We then entered, being followed by another ship of our own size. Two other vessels occupied No. 4 lock and, as showing the immensity of this traffic, the writer noted from the pilot house that, including the ships in the locks, those waiting to enter at each end, and those which had passed through and were starting to the eastward or westward, there was an aggregation of

ships which the captain estimated to total over 150,000 tons in capacity.

We have said that methods of navigation on the Great Lakes are unique, and certainly the end of our journey bore out this statement; for we proceeded, in spite of our length of over 600 feet, to steam up a narrow, winding creek, averaging 250 feet in width, and with turns of 90 degrees, to our destination, the Lorain Steel Works, where we were to discharge. A powerful tug at the bow, a series of alternate full-ahead and full-astern telegraphs to the engine room, combined with an amazing amount of churning up of soft mud, landed us finally at the great ore docks of the company. Before we tied up alongside, the hatch covers had all been opened and four Hulett unloaders, moving into position on the concrete wharf, spaced themselves along our 400-foot length of cargo hold.

These unloaders are one of the most amazing mechanical contrivances of all the many amazing things connected with the United States steel industry. I was standing amidships, looking down into one of the holds, when a voice from the air called out, "Good morning. Did you have a fine passage?" and looking up I saw the huge grab bucket and the vertical bucket leg of an unloader descending to enter the hatch. The voice was from the operator of the grab, who has his cabin inside the "bucket leg" and a few feet above the bucket. As he passed me he pulled a lever, and the two halves of the bucket swung apart until the opening

was over twenty feet. Down sunk the great mass deep into the pile of ore below. Another lever was pulled and the jaws crunched together. The operation of a third lever caused the whole leg and bucket, with its load of ten tons, to rise vertically into the air. Then the grasshopper-like, double walking beam moved back until the bucket was within the pier line, when it opened and let its contents fall into a hopper and thence into a lorry, which immediately was drawn inshore upon the framework of the unloader to discharge itself into ore cars on the tracks below. The walking-beam section of the unloader then moved forward again until the bucket leg was over the hatch, when it descended for another grab. I timed the operation and found that the cycle took just one minute.

This was a ten-ton unloader, but some of the later and larger machines are capable of picking up 17 tons at one grab, and with this in mind it can be understood how the records of unloading mentioned above in this article were achieved.

Thus, we have followed the ore from the time when it was dug out of the Hull Rust pit to the time when it was deposited in the stockpile alongside the blast furnaces, 800 miles distant. At the rate of 20 tons for each scoop the ore is torn loose from its age-long resting place in the ore body; and at 10 to 17 tons to the grab it is picked up and brought ashore at the end of its long journey by water.

CHAPTER IV

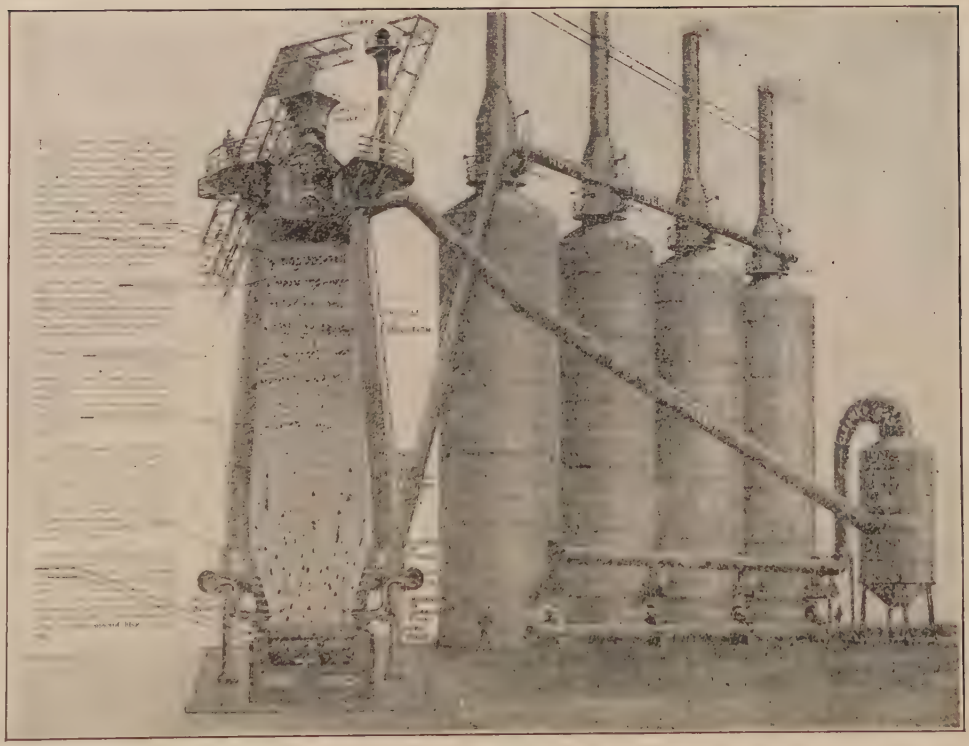
The Blast Furnace

The enormous tonnage of ore brought down the lakes, totaling in a single year over 64 million tons, has to be disposed of quickly at the end of its journey. That part of it which is to be turned into steel on the shores of Lakes Michigan and Erie, is loaded into huge stockpiles at the various steel works; and that which is to be converted in the Pittsburgh district is transferred by unloaders from the ore ships directly to railroad cars.

The vast steel plant at Gary on the southern shore of Lake Michigan is one of the most up-to-date plants in the United States, and handles the largest amount of tonnage. Here the ore steamers enter an artificial canal, 22 feet deep, and 250 feet wide, which extends 4,650 feet inland from the lake. The ore is discharged from the ships by ten Hulett unloaders of the type described in the previous chapter, which deposit it in a long trough parallel with the dock. Working in conjunction with them are ten Hoover & Mason traveling conveyer bridges. These huge structures are 500 feet in length, and each one carries a 15-ton grab-bucket. They dig the ore up from the trough and carry it back to a stockpile storage basin,

from which it is taken, as needed, to the blast furnaces. The enormous storage yard, which is 4,000 feet in length has a capacity of 5,000,000 tons, which is more than sufficient to keep the Gary plant going during the winter months when navigation is suspended and no ore can be brought down.

Parallel with and back of the stockpile are twelve 550-ton blast furnaces, each provided with four hot-blast stoves, which are approximately the same height as the blast furnaces and but little smaller in bulk. Between the stockpile and the furnaces is a long line of elevated storage bins, in two parallel rows, one for coke and the other for ore and limestone. The material from these bins is delivered into electrically operated lorries which carry the materials to the furnace "skips," of which there is a pair to each furnace. The skips run up an inclined railway to the charging platform at the top of the blast furnace, each trip of the skip being made in sixty seconds and its average load consisting of 7,000 pounds of ore, or 6,000 pounds of limestone, or 3,600 pounds of coke. The skip automatically discharges its load into a hopper at the top of the furnace. Within the furnace are two cones. The contents of the skip fall upon the first cone, which is then lowered, allowing the materials to fall upon the second or lower cone. The upper cone is then drawn up sealing the exit, and the lower cone is lowered, discharging the materials into the furnace. This arrangement prevents any escape of the furnace gases.



TYPICAL MODERN BLAST FURNACE GROUP, SHOWING THE BLAST FURNACE IN SECTION, AND ITS SET OF FOUR HOT BLAST STOVES AND DUST CATCHER

The furnace once started is kept going continuously night and day, month by month, and year by year, until repairs become necessary. There are furnaces which have a record of several years' continuous operation. The accompanying drawing and the text which accompanies it explain very clearly the operation of the furnaces and the process by which the iron is separated from the ore and collected at the bottom of the furnace. The air for combustion is introduced at the bottom of the furnaces through a series of water-cooled tuyeres which enter near the top of the hearth. An enormous quantity of air is required for each furnace and this is supplied by huge blowing engines, located at a distance from the furnaces. The air enters at a pressure of about 18 pounds per square inch.

The hot furnace gases are led by a large pipe from the top of the furnace into a dust catcher, and after being cleaned in a washer, they are led through the hot stoves, of which there are four to each furnace, as shown in our drawing. The stoves are cylindrical, plate-steel structures, filled with a honeycomb of firebrick. As the gases enter the stoves (two stoves are heated at a time) a certain amount of air is fed in with them, and the burning gases, as they pass through raise the firebrick within to a high temperature. When the proper heat is reached, the gases are turned into the adjoining pair of stoves. At the same time the cold air from the blowing engines is caused to enter at the bottom of the now heated stoves and, in passing up

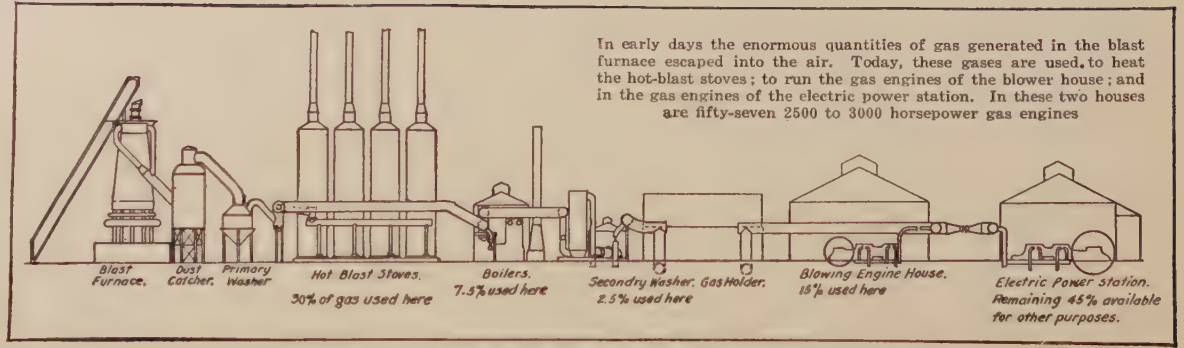

In early days the enormous quantities of gas generated in the blast furnace escaped into the air. Today, these gases are used, to heat the hot-blast stoves; to run the gas engines of the blower house; and in the gas engines of the electric power station. In these two houses are fifty-seven 2500 to 3000 horsepower gas engines
Blast Furnace.
Dust Catcher.
Primary Washer
Hot Blast Stoves. 30% of gas used here
Boilers. 7.5% used here
Secondry Washer. Gas Holder. 2.5% used here
Blowing Engine House. 15% used here
Electric Power Station. Remaining 45% available for other purposes.

Diagram showing the distribution of the furnace gases at Gary

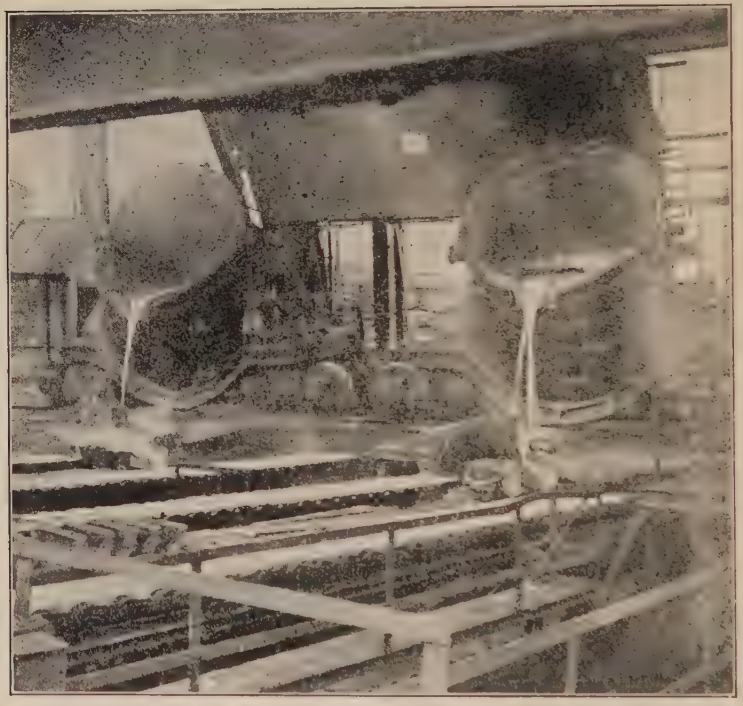
through the honeycomb, it takes up the heat previously given up by the furnace gases, and enters the blast furnace at a high temperature, thus restoring to the furnace a large measure of its heat.

The operation of the blast furnace, as we have said, is continuous, and the temperature varies, as shown in the accompanying drawing, from that of the molten iron (3,500 degrees) in the hearth at the bottom to that of the cold charge as it is fed in at the top. At regular intervals the slag and the hot metal are separately drawn off into large ladles, the slag being hauled away to be crushed and utilized in the cement mills, and the hot metal being hauled to the mixers and thence to the Bessemer converters, or to the open-hearth furnaces as will be described in subsequent chapters.

Referring again to the accompanying drawing, it should be explained that the two right-hand stoves are being heated by the burning gases, which are led in and ignited at the bottom, the valves from the cold-air pipe just below being closed. At the top of these two stoves, the valves opening to the hot-blast pipe are closed and the products of the burning gases are passed out through the tall smokestacks above the stoves. At the same time the valves opening from the cold-air duct at the bottom of the two left-hand stoves are open; the gas valves just above them are closed; the valves controlling the smokestacks are closed; and the valves opening to the hot-blast pipes are open.

In laying out the Gary plant, it was possible to util-

ize all the past experience in the steel industry and effect large economies. Chief among these is the utilization of the blast-furnace gases for raising steam in



THESE GREAT LADLES HAVE BROUGHT MOLTEN IRON FROM THE BLAST FURNACE, AND ARE POURING IT INTO PIG MOLDS. THE MOLDS TRAVEL FORWARD BENEATH THE LADLES AND ARE FILLED SUCCESSIVELY

batteries of boilers; in operating gas engines for running the furnace blowers, and other gas engines for operating generators for the supply of power and light for the vast Gary plant. There will be some among our readers who, like the writer, remember the time

when no attempt was made to save the enormous and valuable volumes of gas which poured out of the top of the blast furnaces. The first attempt to save part of these gases was to burn them underneath steam boilers and secure power for the operation of the blowers, etc., by steam engines. A later development is that carried out at Gary. The diagram which we present gives the distribution now made of the furnace gases, of which the twelve furnaces at Gary produce *every hour* 40,300,000 cubic feet of furnace gas. Of this total amount 30 per cent is used in heating the hot stoves. The steam power plant uses 7.5 per cent. The primary washers for the hot-blast stoves and the secondary washers to clean the gas again before it goes to the gas holders, use 2.5 per cent of the gas. Then the great blowing engines use 15 per cent, and the remaining 45 per cent is available for running the gas engines in the electric power station. The blast-furnace gas serves to operate fifty-seven 2,500 to 3,000 horsepower gas-driven generators and blowing engines.

Returning now to the process of reduction in the blast furnaces, the limestone is used to "draw" the silicon, sulphur, manganese, and various other ingredients out of the melting charge. In this process there is formed a frothy substance (which includes ashes of the burning coke and various products of combustion which do not escape with the gas) which floats on the top of the molten iron. This is the slag. Much of the sulphur and the phosphorus, about three-quarters of the man-

ganese, and more or less silicon will remain in the molten iron.

Coke is used almost exclusively in the blast furnaces of the United States. It is made by baking bituminous coal for 12 hours in closed ovens, over 75 per cent of a ton of coke being produced from a ton of coal. The blast furnace coke must have special qualities. It must be strong enough to sustain without crushing part of the huge burden of 1,500 tons of the load in the furnace. It must be porous, so that the hot blast may pass freely through it. Coke consists of about 88 per cent carbon, and it is the burning coke together with the red-hot blast as it comes from the stoves, which completes the final process in the lower part of the furnace of melting the iron and the slag. The pig iron, as tapped from the furnace, contains from 3½ to 4 per cent of carbon, which is subsequently reduced in the Bessemer converter, or the open-hearth furnace.

CHAPTER V

The Bessemer Converter and the Electric Furnace

In Chapter IV we saw that in the blast furnace iron was separated from iron ore by means of the fierce heat resulting from the combustion of coke, through which great volumes of heated air were continually being driven. The resulting metal, as it is tapped from the bottom of the furnace, is liquid cast iron, or "pig" as the furnace man calls it.

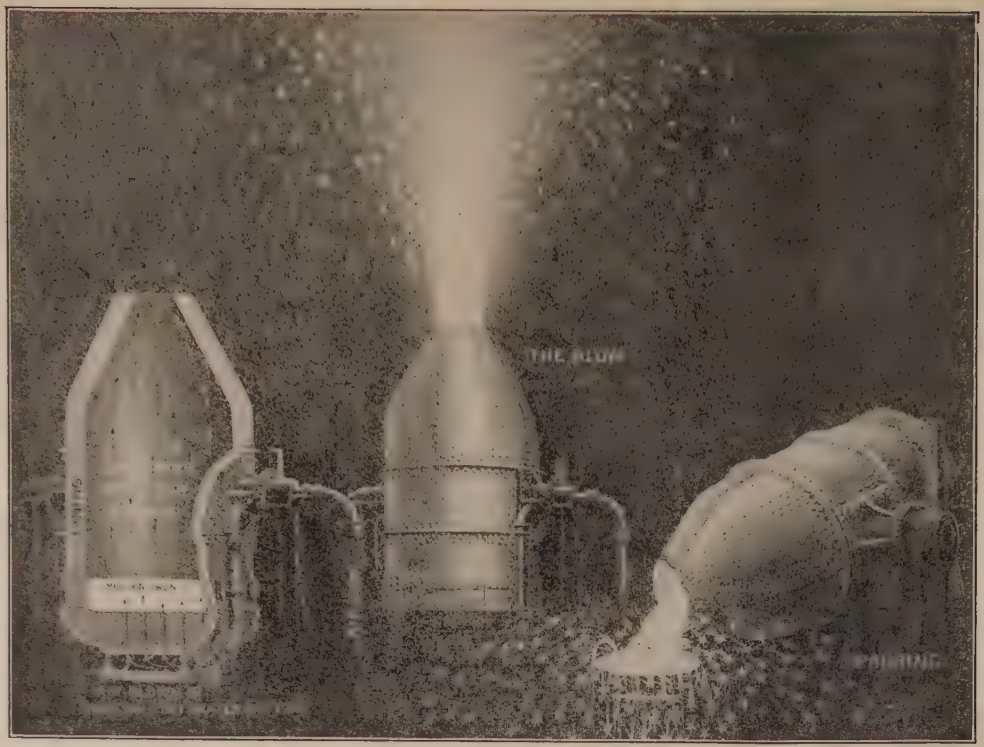
Now, although cast iron is a useful metal in the constructive arts, its range of usefulness is greatly limited by the fact that, though its compressive strength is high, its bending and tensile strength are low. It lacks the ductility, toughness, elasticity, and all-round strength of steel. The absence of these qualities is due to the excessive amount of carbon present, as compared with that in steel. There is also an excess of silicon, a constituent of sand and rocks; phosphorous, as used on the household match; sulphur, which the "kiddies" used to take (and may do yet, for all we know) in "sulphur and molasses"; and manganese.

And as fire is the principal agent in getting the iron out of the iron ore, so fire is used to turn the iron into steel. This it does by burning out the above-named

impurities, either in the Bessemer converter or in the open-hearth furnace. The Bessemer converter, developed in England by Henry Bessemer about 1855, was an epoch-making invention in the steel industry. By many, because of its revolutionary effect on modern industry, it is regarded as the greatest of all inventions; for without it the production of cheap steel in unlimited quantities would have been impossible. It was admirably adapted to iron made from ores that were low in phosphorous content. As the choicer ores became depleted, the open-hearth furnace of Siemens-Martin was developed; and in this furnace iron that is high in phosphorous can be treated successfully. Today, about 25 per cent of the steel is made by the Bessemer and 75 per cent by the open-hearth method.

Steel-making is highly spectacular all the way from the vast open mines at Missabe to the rolling of the steel into its thousand-and-one shapes in the mills; but nowhere does it present such a dramatic and awe-inspiring sight as in the converting mill.

The converter is a barrel-shaped steel vessel, varying from 10 to 16 feet in interior diameter, and from 12 to 20 feet in height. It is closed at the bottom, and is drawn in at the top, as shown in the sectional view on another page. At its mid-height it is supported on trunnions. An air pipe is led in through one of the trunnions and continues down to an air chamber in the base of the converter. The interior is lined with 12 to 18 inches of refractory material to



IN THE BESSEMER CONVERTER STREAMS OF AIR ARE BLOWN THROUGH THE MOLTEN IRON, BURNING OUT THE SILICON, CARBON, MANGANESE, ETC.—THE MAJOR STEP IN CONVERTING IRON INTO BESSEMER STEEL

protect the steel shell from the fierce heat. The bottom is perforated with from 150 to 200 one-half-inch holes, leading from the air chamber to the interior of the converter.

Now let us return to the blast furnace. Here, at intervals of every four hours, the clay plug which seals the outlet from the bottom of the furnace is broken through and the molten iron is run into a train of steel ladles, which are drawn by a locomotive to the mixer, a large horizontal cylinder lined with firebrick, which can hold 1,300 tons of metal at one time. The mixer here spoken of is part of the plant of the South Works, Chicago, of the Illinois Steel Company. The object of the mixer is to form a large reservoir, from which the hot metal can be drawn as required by the converters.

From the mixer the hot metal is emptied by rotating the mixer on its axis, and pouring its contents into ladles for transport to the converters. The converter is turned down into a horizontal position, and a charge of 10 to 25 tons is poured in from the ladle. The air blast is then turned on and the converter swung back into the vertical position. The air, under a pressure of about 20 to 25 pounds to the square inch, is now forced up through the molten iron in from 150 to 200 separate streams, and its oxygen, combining with the carbon, silicon and manganese in the iron, sets up a violent combustion, and raises the temperature of the mass until it reaches the stage known as the boil. The

process continues for from 10 to 15 minutes, at the close of which the impurities, including practically all of the carbon, have been burned out and only pure iron remains.

The oxygen of the air first burns away the silicon and manganese and finally the carbon. The color and density of the flame issuing from the mouth of the converter clearly indicate to the skilled operator what is going on inside. As the silicon and carbon begin to burn, an orange-yellow flame, edged with blue, streams from the nose of the vessel. Then, as the carbon begins to burn there is a change to a bright flickering flame which rushes violently forth, accompanied with great streams of sparks. Then the flame dies down. The process lasts only from 10 to 15 minutes; but the fierce combustion raises the temperature of the metal in that short time from 2,000 degrees to as high as 3,000 degrees.

We have spoken of the spectacular effect afforded by a converter mill in full blast. The agitation of the molten mass, as the air rushes through it, produces a dull reverberation, which mingles its deep note with the steady roar of the hot and brilliantly colored gases, as they pour from the mouth of the converter. Every now and again small particles of white-hot metal are thrown high into the air and fall in a thick rain of brilliant coruscations to the ground.

But the mere burning out of the undesirable elements does not give us steel; for what we have left in the con-

verter is merely an unadulterated and "characterless" iron. It must now be changed into steel by putting back into it, with great exactness, a certain amount of carbon, manganese, silicon or other substances to produce the kind of steel required. Accordingly, after the converter is turned over and before its contents are poured into a ladle, a carefully weighed amount of these substances in the form, let us say, of spiegeleisen, is introduced in molten form into the converter, to give the small amount of manganese, silicon and carbon required in the finished steel.

The ladle is now lifted and a train of cast-iron ingot molds, with two or three molds to the truck, is drawn beneath the "pouring stand," and the steel is run into the molds through a nozzle in the base of the ladle.

The Bessemer converter has been replaced very largely by the basic open-hearth furnace, which is capable of handling satisfactorily iron made from grades of ore containing large percentages of phosphorus. The Bessemer converter does its work upon the metal in from 10 to 15 minutes, whereas the open-hearth furnace requires from 7 to 12 hours. Speaking broadly, the open-hearth process permits the metallurgist to keep in closer touch with the reactions that are going on within the furnace, and, by skillful treatment, he is able to secure with accuracy the exact amounts of carbon, manganese, etc., necessary to give him the steel which he wishes to produce.

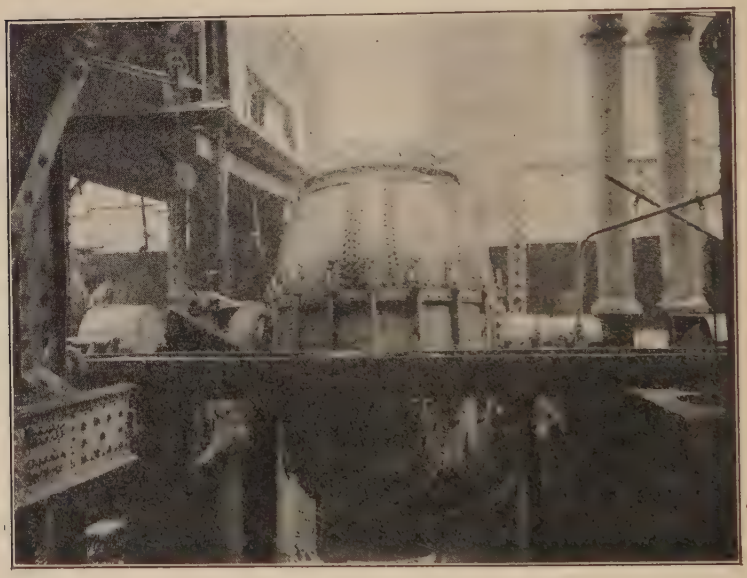
Excellent as the open-hearth furnace process is, the

steel maker has aimed to get even better results by using the electric arc as his source of heat in the furnace. Much experimental work has been done, and out of this has come the Heroult electric furnace, of which we show on another page a cross-section. The Illinois Steel Company have been painstaking and successful in the development and use of electric refining, and their two 25-ton furnaces are among the largest and most successful in existence. The United States Steel Corporation has four of these 25-ton electric furnaces, and the Corporation built two 40-ton Heroult electric furnaces for the United States Navy, which operated very successfully during the war.

The furnace, 16 feet in diameter, has a plate-steel shell one inch in thickness. The bottom is carried on toothed rockers and tracks, on which the furnace is tilted to empty its contents. Large gear wheels are geared to a 140-horsepower motor, which tilts the furnace, by means of a connecting rod. The furnace is lined with three different materials; first 4½ inches of fire-brick; next to that a lining of magnesite brick 9 to 13½ inches in thickness; and above the last named is spread about 13 inches of burned magnesite. The dome-shaped roof, 12 inches thick, is of silica brick.

In the roof are three equally spaced openings for the electrodes, 20 inches in diameter, which are formed of amorphous carbon. They are carried by horizontal arms that project over the furnace, and are adjusted by heavy, vertically moving rods. Heavy copper cables

and copper bars carry the current from the adjoining transformer house to the holders that grip the carbon electrodes. The bottom of the electrodes is maintained with a clear spacing of about three-quarters of an inch between them and the surface of the slag.



A BESSEMER CONVERTER IN FULL BLAST

At the South Chicago Works, the electric furnace is used in conjunction with 25-ton Bessemer converters and large tilting basic open-hearth furnaces of 200 tons capacity. The capacity of the electric furnace is 25 tons and the charge consists of all-blown molten Bessemer metal, or a charge of molten open-hearth metal from the 200-ton tilting furnaces is used instead of Bessemer metal. The current is three-phase, and the

amperage, automatically regulated, runs from 6,000 to 14,000 per phase. The current comes in to the transformer house at 2,200 volts, and is transformed to 110 volts. If the furnace is producing .80 carbon steel, the temperature will rise to about 2,750 degrees; if it is making .08 carbon steel, the temperature will rise to 2,850; and for certain products it will reach 3,000 degrees Fahrenheit.

It is needless to say that the perfect control of the temperature at all times during the process of refining, as well as of the chemical reactions, and the possibility of making many sample tests during the heat, are among the great advantages of electric refining.

The sequence of operations in refining a charge of metal, is as follows.

First: Twenty-five tons of blown molten Bessemer metal or open-hearth metal is poured in.

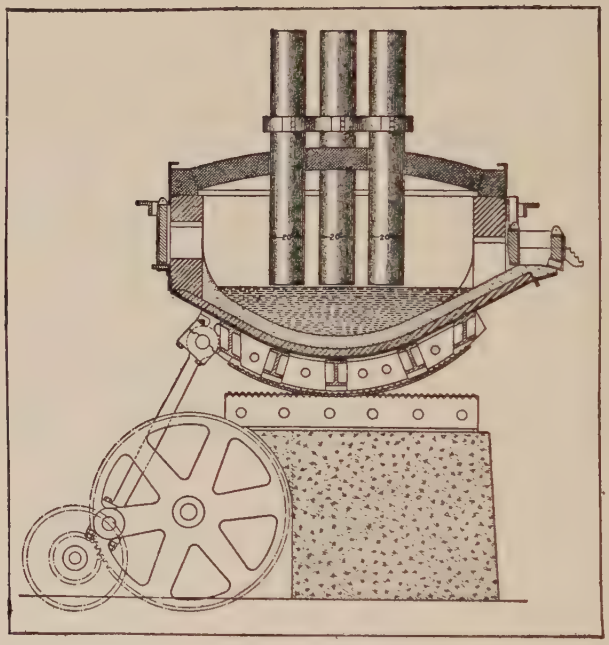
Second: The electrical current is turned on.

Third: 1,400 pounds of lime, and if Bessemer metal be used, 900 pounds of iron oxide are added. This forms a slag for the removal of the phosphorus.

Fourth: After the phosphorus has been reduced from .09 to .008 of 1 per cent, the preliminary or oxidizing slag is removed from the furnace, and a new (reducing) slag is made by shoveling in 1,100 pounds of burnt lime, 200 pounds of sand, 200 pounds of fluorspar, and 200 pounds of coke dust—all for the purpose of deoxidizing the metal and eliminating sulphur.

Finally, when the metal in the charge has been thor-

oughly refined, the proper amount of manganese, nickel, vanadium, chromium, or other alloy is added to pro-



SECTION THROUGH ELECTRICAL FURNACE. THE CURRENT, PASSING THROUGH THE THREE 20-INCH ELECTRODES AND THE METAL CHARGE, RAISES THE TEMPERATURE TO AS HIGH AS FROM 2,850 TO 3,000 DEGREES

duce the alloy steel required. The treatment, as above described, lasts about four and one-half hours.

CHAPTER VI

The Open-hearth Furnace

It was because the Bessemer converter rendered it possible to make steel with great rapidity and at low cost, that its inventor, Henry Bessemer, will always remain the outstanding figure in any history that may be written about the steel industry. To think of steel is to think of Bessemer.

It was in 1854, that he invented his Bessemer or pneumatic process in England, and about the same time William Kelly of this country, quite independently came out with a process of making steel, also using a blast of air as the means. After considerable litigation, a compromise was made, and today we know the pneumatic process by the name of Bessemer.

In 1861, Siemens developed his regenerative furnace, the underlying principle being as follows:

The hot gases are passed over the furnace body and thence through a series of checker brick and on to the stack. The direction of the flame is then reversed, the air being taken through these hot checkers, absorbing heat and thus yielding a high temperature on uniting with the fuel. This continued reversal leads to a gradual increase in flame temperature, which is today the basis of open-hearth work.

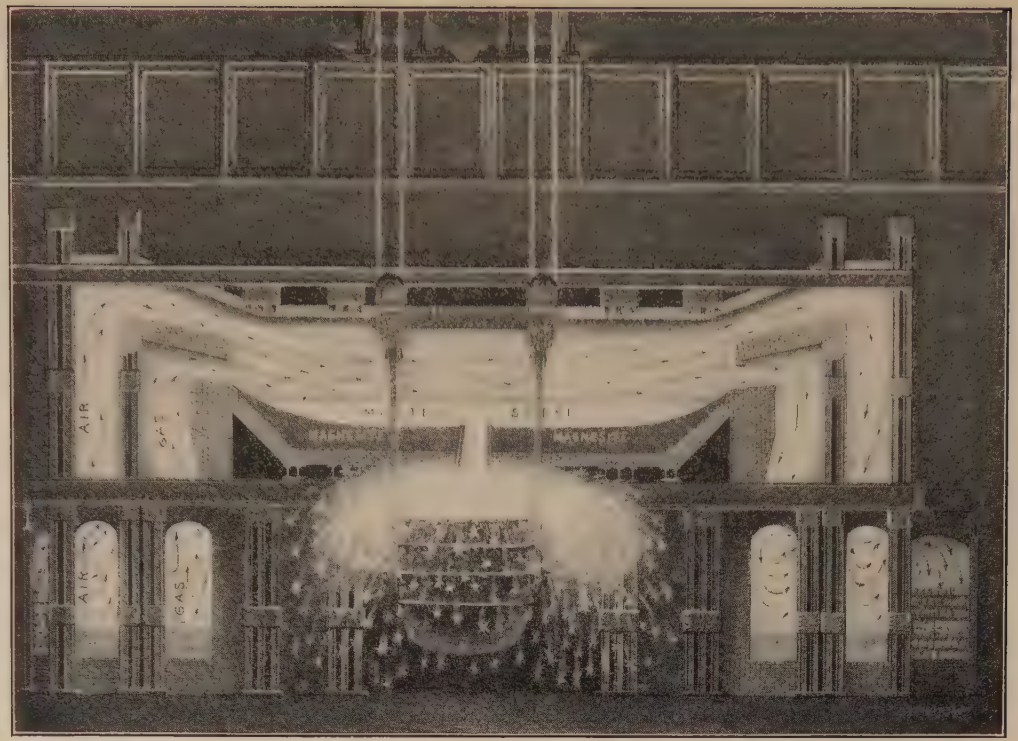
The limitations of the Bessemer process did not hold for the open hearth, since it became possible to use materials of a greater variety. The process of refining is much slower, ordinarily from 8 to 12 hours; but it became possible to exercise a very close control of the reactions, make frequent tests of the metal in the bath, and secure a steel of the exact composition required. So marked are these advantages, that in the specifications for high-class construction, such as bridge building, where a very exact relation between the working stresses and the strength of the materials must be secured, there is an invariable call for open-hearth steel.

The advantages of the open-hearth process have been summed up as follows:

1. By the use of ore as an oxidizing agent and by the external application of heat, the temperature of the bath, that is, of the materials in the furnace, is made independent of the purifying reactions, and the elimination of the impurities (carbon, silicon, manganese, etc.) can be made to take place gradually; the temperature and composition of the bath being under much better control than in the Bessemer process.

2. For the same reason, a greater variety of raw materials can be used and a greater range of products made.

3. A very important advantage is the increased output of finished steel which can be secured from a given amount of pig iron; hence fewer blast furnaces are



SECTION THROUGH AN OPEN-HEARTH FURNACE, SHOWING THE GAS AND AIR FLUES, AND THE "BATH" IN WHICH 100 TONS OF IRON ARE BEING REFINED TO STEEL. WHEN THE PPOCESS IS COMPLETE, THE STEEL IS TAPPED INTO A LARGE LADLE, SUSPENDED FROM AN OVFRHEAD TRAVELING CRANE

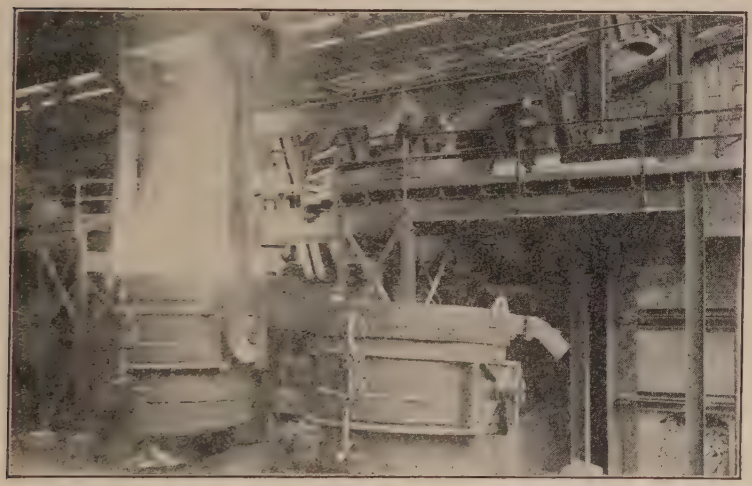
required to produce the same tonnage of steel. This is explained by the fact that the Bessemer process uses all iron in molten form, whereas the open-hearth process can use molten iron in smaller proportion of the total charge, together with scrap.

4. With the development of the basic process, it was found that the greatest advantage of the Siemens-Martin over the Bessemer was the elimination of phosphorus. While the basic Bessemer process requires pig iron with a phosphorous content of 2 per cent or more in order to maintain the temperature necessary for the reactions, the basic open-hearth process permits the use of iron of less limited phosphorus content.

In 1908, the open-hearth process surpassed the production of the Bessemer and today it may be said, roughly speaking, that the open hearth produces one hundred tons of steel for every twenty made by the Bessemer process. Natural gas, which was formerly used in open-hearth furnace work, because of its severe limitations in supply has been replaced as a fuel by producer gas, a product from the gasifying of coal in gas producers; by tar and by-product gas; and in later years by fuel oil.

The open-hearth furnace, as shown in the accompanying illustration, is a large rectangular structure approximately 15 feet wide by 35 to 40 feet in length. At each end of the furnace are two large openings or ports, one to admit air and the other gas. The roof is of silica bricks, 3 inches by 9 inches by 15 inches deep.

This highly refractory material is built in the form of a flat arch to give it strength and stability; and the whole furnace is held in place and tied together by heavy beams and tie-rods. The hearth or bottom of the furnace rests on steel plates which are carried by beams or channels resting on piers entirely independent of the rest of the structure.



TAPPING THE STEEL FROM AN OPEN-HEARTH FURNACE INTO A LADLE. THE LADLE IS SUSPENDED BY THE TWO MASSIVE HOOKS FROM AN OVERHEAD ELECTRIC TRAVELING CRANE. SOME OF THESE LADLES CAN HOLD 100 TONS OF MOLTEN STEEL

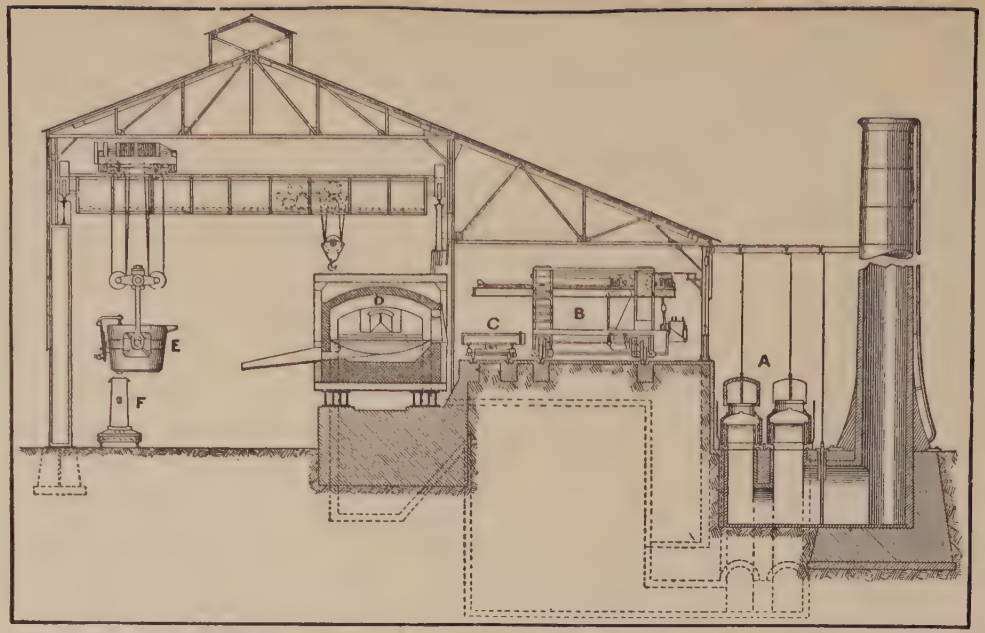
In a basic furnace the bottom is made up of several courses of clay brick, upon which is placed a deep lining of magnesite, curved upwardly all around to form a trough-like basin. This magnesite—a highly refractory material, is mixed with ground basic slag, and it is then set by slow heating and gradually brought up

to a high working temperature, thus fusing the bottom. The acid furnace is constructed in the same fashion, except that silica sand is used in place of grain magnesite. Furnaces today are practically all basic, and range from a capacity as small as 5 to 15 tons for making special steels to as large as 125 tons. The average capacity today is from 60 to 75 tons per heat.

The open-hearth process varies in different districts, depending upon the available pig iron and the scrap conditions. A typical plant in the Pittsburgh district charges a furnace as follows:

Raw materials, such as limestone, ore and scrap, are assembled in a stock yard. In some cases the limestone and ore are carried in bins and dropped directly into charging boxes, which are usually 20 inches wide, 20 inches deep and 6 feet in length. The various scrap is loaded into the boxes by magnets. All these materials are then assembled into a "heat." Then a small engine pulls the materials into the open-hearth building, leaving it to be handled in the next step by the almost-human charging machine. This machine has an arm which locks into the end of the charging box, and can be moved to and fro and revolved. The door of the furnace is opened, the box is picked up and thrust into the furnace, the arm is revolved, dropping the material on the hearth of the furnace, and the box withdrawn.

Limestone is placed on the basic bottom, then ore, then a certain amount of scrap, approximately 40 per cent of the total metallic charge. The charge is melted



To the extreme right is the stack. Then follow: *A*, air and gas reversing valves; *B*, charging machine: *C*, buggies, from which charger picks up boxes of "mixture," thrusts them into furnace *D* and empties them; *D*, furnace, with charging door (right) and pouring spout (left); *E*, ladle cranes, with ladle *E* over mold *F* pouring an ingot

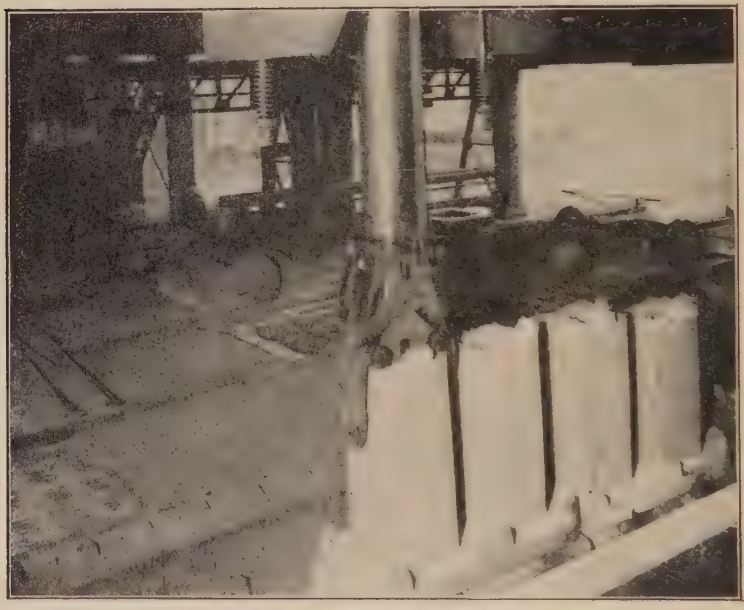
SECTIONAL VIEW, SHOWING RELATIVE POSITION OF ELEMENTS OF A OPEN-HEARTH PLANT

by burning fuel in conjunction with the highly preheated air that has come through the checker work, as mentioned before, thus yielding a very high temperature of combustion. With the reversals in flame direction at intervals of 20 to 30 minutes, the charge is gradually melted down. The mass is heated until the scrap is white hot and slightly fused; then molten pig iron is added. This is taken from a mixer, which is a storage body for the hot iron coming from the blast furnaces, whereby uniformity in the quality of the iron is secured and a steady supply of hot iron for the open-hearth furnaces is maintained. The mixers are usually of from 500 to 1,200 tons capacity.

With a scrap content of 40 per cent of the metallic charge, the molten iron would then be 60 per cent of the total when added. With the addition of this iron there occurs a lively reaction, during which almost all of the silicon, manganese, phosphorus and part of the carbon are oxidized or burned out by the oxygen, the first three forming compounds that slag with the iron oxide and join the iron and lime silicates which have already been melted. At the end of two or three hours about 80 per cent of this slag is drawn off. The ore acts on the carbon for three or four hours longer, the limestone being decomposed by the heat; and the carbon monoxide, bubbling up through the bath, exposes part of the metal to the flame, oxidizes it, and completes the purification started by the ore reactions. The heat is then worked until the carbon in the bath is approxi-

mately that required in finished steel. Tests are taken of the heat and broken, the fracture is examined and expert melters read the carbon.

When the heat is considered ready, a steel bar is thrust through a hole in one of the doors and the



THIS POWERFUL, ELECTRICALLY-OPERATED TONGS GRIPS THE INGOT MOLDS AND LIFTS THEM CLEAR OF THE STEEL INGOTS

retaining plug in the rear of the furnace is knocked out, allowing the steel to run through a trough into a ladle, which has already been heated by gas to dry out all moisture in the lining. The steel is then purified by the addition of certain deoxidizers, such as ferro-silicon and manganese, the greater part of the manganese

remaining in the steel in order to meet the desired specifications. The necessary carbon is added either in the form of finely granulated coal or of molten spiegeleisen —a high-manganese iron containing sufficient carbon and manganese to give the desired results. The slag being lighter than the steel, floats on the surface and much of the slag runs over the side of the ladle into pits or boxes kept for that purpose.

At a signal from the melter a massive crane, electrically operated, is moved in front of the furnace, drops its arms under the lugs of the ladle, lifts it and carries the mass of molten steel weighing often as much as 100 tons to the pouring platform, where the retaining plug or stopper is lifted up and the steel, through this aperture in the bottom of the ladle, pours into cast iron ingot molds, these ingots varying in size and weight, according to the product into which they are to be rolled. In an average size heat of 60 to 75 tons, the ingots will weigh approximately three and one-half tons each and be about 20 inches by 22 inches at the bottom, 6 feet or slightly more in length, and slightly tapering towards the top.

CHAPTER VII

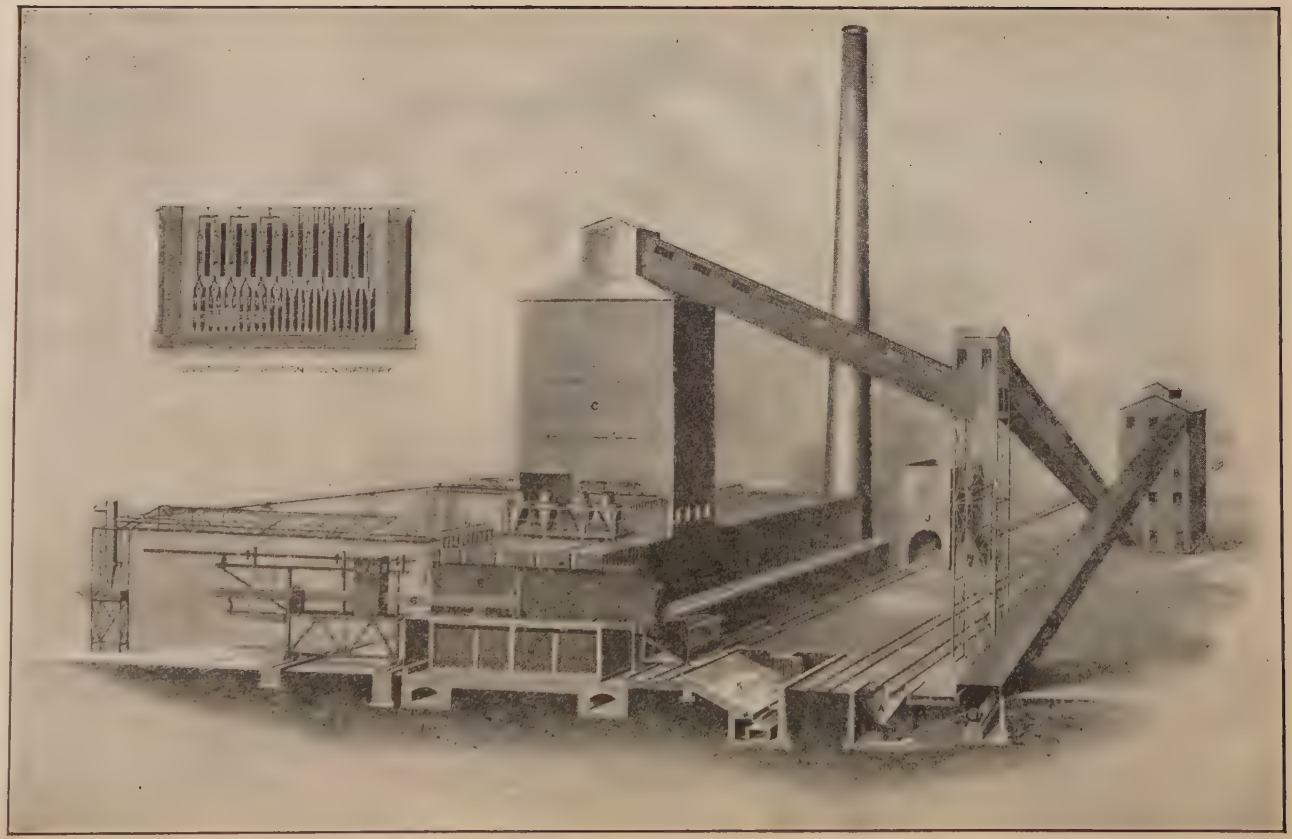
The Manufacture of Coke

The story of steel falls naturally into two divisions, the first covering the process of manufacture from the ore mine to the steel ingot, the second the fabrication of the ingot into a multitude of finished products such as rails, plates, I-beams, angles, piping, wire, nails and what not. Thus far we have dealt with the iron mine, the ore steamer, the blast furnace, the converter, and the open-hearth furnace with their ultimate product the steel ingot. But before passing on to the rolling mills, a chapter must be devoted to the manufacture of coke—the fuel upon which the blast furnace depends for its mighty reactions. The large part played by coke is realized when we learn that in 1923 (a remarkable year in the history of steel making), no less than 40,351,000 tons of coke were consumed in the blast furnaces of the United States. Coke, as we all know, is made by the carbonization of coal, and it is the residue which is left after the volatile constituents of the coal have been driven off.

In the early days of the steel industry the coking process was carried on in what is known as the beehive coke oven—which was circular in plan and was closed

with a domed roof provided with a central opening for the escape of the gases. The coal was laid on the flat floor and no attempt was made to recover the gases, which went to waste. In the manufacture of illuminating gas, where it was sought to recover the volatile elements from the coal, the coke was a matter of secondary consideration. The carbonization was and is now carried on in closed retorts, heated from the outside, the gas being purified and its by-products recovered before it is passed into large gas holders.

It was inevitable that in the steel industry the efforts of inventors should be directed to the recovery of the very valuable by-products, and gradually, during the past 75 years there have been developed various types of coke ovens, until a modern battery of ovens, such as that shown in the illustrations, together with its elaborate by-product plant, forms one of the most admirable and efficient sections of any large steel-making plant. Not only is it now possible to produce a coke possessing the special qualities called for by the blast-furnace operator, but from the gases which formerly went to waste there is now recovered a whole series of valuable by-products, and the gas itself is being used as fuel both in the coking ovens and in various furnaces throughout the steel plant. The modern coke oven, such as the Koppers installation herewith illustrated, has brought about one of the most important economies in the whole range of steel manufacture, an economy of fully 30 per cent having been secured in the manufac-



THE GENERAL LAYOUT OF A KOPPERS-BECKER BY-PRODUCT COKE OVEN. THE GAS DISTILLED FROM THE COAL IS LED TO A SEPARATE PLANT FOR THE RECOVERY OF ITS VALUABLE BY-PRODUCTS

ture of coke as compared with the older and most wasteful processes.

In the year 1906 the United States Steel Corporation sent a committee of engineers and works managers to examine the by-product coke plants of the United States and Europe, and they finally selected the Koppers Cross Regenerative Coke Oven as representing the best of the systems in operation, and recommended to their company the erection of 280 ovens of this type. The Steel Corporation informs us that the installation of the by-product ovens is saving $8,000,000 annually in their works alone, and that it is probable that at least another $8,000,000 is being saved by the Koppers and various other by-product coke ovens among the independent steel concerns.

The Cross Regenerative By-product Coke Oven as herewith illustrated, is a narrow rectangular chamber built of silica brick, which in its most modern dimensions will have an average width of 14 inches, height of 12 feet, and length of 40 feet. These ovens are arranged side by side in one long structure which may extend for several hundreds of feet. The ovens are separated from each other by a series of vertical flues in which burning fuel gas provides the heat necessary for coking the coal in these retorts. Directly beneath each retort is an individual regenerator, similar in its principles of operation to the hot stoves which we illustrated in our articles on the blast furnace and the open-hearth furnace. In these regenerators the air for com-

bustion is pre-heated. The two ends of each oven are closed with tall narrow doors, sealed with clay. The heating gas passes from the gas holder through the fuel gas main and into the risers opposite each oven, and the air for combustion is heated to a high temperature by being drawn through the brick checker-work of the regenerator below. The heated air meets the incoming gas stream at the base of the vertical flue, whence the burning gases pass upward in the flue. From the top of the vertical flues the hot gases of combustion pass through suitable flues over the top of the vertical flues and down into the opposite regenerator. Here they give up a large part of their heat to the brick checker-work. After this has continued for about 20 minutes, the flow of air and gases is reversed, the fresh air passing up through the heated checker-work, recovering and returning to the oven flues all the heat except that which (about 500 degrees Fahrenheit) is required to produce the necessary stack draft. It is impossible, within the limits of this chapter, to go into more detail in explaining this operation, and it must suffice to say that the flow of the gases is automatically reversed at regular intervals, and that the flow is so adjusted that the charge of coal is heated evenly throughout the whole height and length of the oven, and a coke produced which is firm; that is to say, which will not shatter, and which has sufficient crushing strength to bear in the blast furnace a part of the enormous load of 1,300 tons of the burden over head. A uniform transfer of

heat to the charge of coal in the oven has been secured by narrowing the width of the ovens which formerly were about 20 inches wide as against a present width of 14 inches.

Our illustration gives an excellent idea of the general layout of an up-to-date plant. Coal brought in on rail-

COAL STORAGE YARD FOR COKE MAKING. THE COAL IS CARRIED FROM THE YARD TO THE COKE OVENS BY CONVEYORS

road cars is discharged into hoppers *A*, as shown in the right-hand foreground of the illustration. From the hoppers it is fed on to an inclined belt, which in turn discharges it on to a long 36-inch belt on which it is conveyed to the top of the breaker building *B*, where the coal is broken up to pass through a 1½-inch screen, and here at the same time the refuse, such as slate, bits

of iron, etc., is removed. From the bottom of the breakers a 30-inch belt on an incline of 20 degrees, carries the screened coal to a transfer tower, and thence it passes over another 30-inch belt, to the head house above the large coal bunker *C*, which has a capacity of 1,000 tons and serves a complete battery of ovens. Below the bunkers and traveling on the roof of the ovens is a lorry, containing four cone-shaped hoppers *D*. The bottoms of these hoppers register with a series of four holes in the top of each retort, through which the exact amount of coal to fill the retort is discharged.

During the process of coking the gases pass through the roof of the retort and enter a 60-inch collecting main *L*, which extends the full length of the bank of ovens, the temperature of the gas being approximately 1,000 degrees Fahrenheit. In the collecting main the gas is sprayed with tar and ammonia liquor, the sprays being located at every four feet along the main; and here it is cooled to 210 degrees Fahrenheit. The heavy tars are condensed out of the gas in the collecting main and washed along by the flushing liquors to the suction main, from which it is collected through traps. The gas is led through pipes *N* to the coolers, and ultimately to the by-product plant, which is housed in its own separate building.

When the coking of an oven is completed, the end doors are removed and the coal is discharged by means of a large, powerful, electrically operated machine known as the "pusher," which is mounted on tracks

running parallel with the ovens. The pushing is done by a horizontal bar *G*, carrying at its further end a vertical plate, whose area is slightly less than that of the cross section of the retort. As the red-hot mass of coke emerges, it falls into a quenching car *H*, which is of sufficient size to contain a full charge. A little electric engine now runs the car into the quenching

TO RIGHT AND LEFT ARE TWO LONG LINES OF COKING OVENS. OVERHEAD ARE THE CONVEYORS WHICH CARRY THE COAL TO THE CIRCULAR STORAGE BINS, FROM WHICH IT IS FED BY TRAVELING LORRIES TO THE OVENS

house *J*, where sprays of water fall upon the coke, and cool it off. The coke is then discharged through the side of the car to an inclined coke wharf *K*, from which it falls on to a coke conveyor belt and ultimately finds its way to the charging hoppers of the blast furnaces.

In addition to the tar and ammonia liquor recovered in the collecting main and washers, a number of the highly valuable by-products, including benzol, are re-

covered after the gas enters the by-product house, an adequate description of whose plant and processes would call for a separate chapter.

As showing the great saving achieved by the substitution of the by-product for the beehive oven, consider the following facts: In the beehive type about 60 per cent by weight of the coal is recovered as coke; by the by-product type about 75 per cent. The 12 blast furnaces at Gary consume some 6,000 tons of coke per day, and to produce this about 8,000 tons of coal are needed in the ovens. If beehive ovens were substituted for the by-product ovens at Gary, it can be realized that the coal consumed daily would be enormously increased. The annual saving, indeed, has exceeded 2,000,000 tons of coal. And to this must be added the saving in the by-products recovered from the volatile constituents of the coal, which are entirely lost in the beehive ovens, being discharged into the air. The by-product plant at Gary forms one of the most interesting developments in this great establishment. There is no branch of this or any other modern steel plant that expresses more emphatically the highly developed technique of the United States steel industry.

We close with the following analysis of results obtained in one of the latest types of Koppers ovens:

Gross coking time	11 hrs. 46 min.
Net coking time	11 hrs. 26 min.
Coal per oven per day	28.7 tons
Total coke yield—per ton of coal	75.75 per cent

Furnace coke yield—per ton of coal	63.07 per cent
Domestic coke yield—per ton of coal	6.98 per cent
Breeze—per ton of coal	5.70 per cent
Total gas yield—per ton of coal	11,360 cu. ft.
Tar yield—per ton of coal	12.37 gallons
Sulphate yield—per ton of coal	25.21 pounds
Light oil yield—per ton of coal	4.03 gallons

In addition to the advances which have been made in coke oven design in the United States, we are informed by Joseph Becker, a leading authority on by-product coke ovens, that "the organizations operating the coke ovens consist generally of technically trained men with good practical experience; the latter not being generally the case in Europe." As a result of these factors, coupled with the use of silica brick for the furnaces, the same authority tells us, that, as compared with Europe, "America can make the same quantity of coke from the same coals in one-half the number of ovens."

CHAPTER VIII

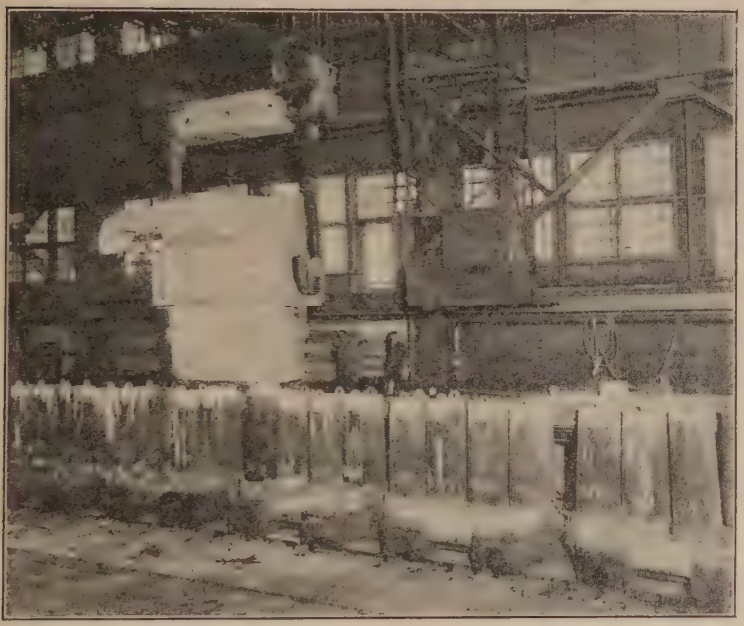
Rolling Steel Rails

Thus far in the story of steel we have described the successive processes by which steel is produced from iron ore. We have seen that the principal agent in the chemical reactions in the production of steel is fire; first by the combustion of coke under hot-air blast in the blast furnace to produce pig iron, and then in the fierce heat of the converter, the open-hearth furnace and the electric furnace, to refine the pig iron to steel.

The succeeding chapters will deal with the manufacture of the steel ingot into some of the principal finished steel products; and as fire is an essential agent in the production of the ingot, so we shall see that the steel rolls of the rolling mill, assisted by furnace heat, are an essential agent in shaping the steel ingot into the multitudinous finished forms of the steel industry.

It may safely be said that every one of us, at some time in our youthful days, has watched the cook take a lump of dough and roll it down to the desired shape with her rolling-pin, and it is this simple process of which the steel manufacturer avails himself to reduce the bulky white-hot ingot to the desired size and shape

—with this important difference, that in the rolling mills the work is done between two or more stationary rotating rolls, driven by powerful steam engines or electric motors.



TAPPING THE STEEL FROM THE BOTTOM OF THE LADLE TO THE INGOT MOLDS

The present chapter deals with the manufacture of steel rails; and regarding the rail let it here be said that, in the broad field of the steel industry, there is probably no single material that is called upon to perform such heavy and trying duty as the steel rail. It is subjected to every conceivable kind of stress, and practically all these stresses are heavily dynamic in

character. In the first place, a 33-foot rail is practically a continuous girder having about 22 evenly spaced piers or supports—the ties. The loads which come upon it are heavily concentrated; they are imposed where the successive wheels of locomotive or cars bear upon the rail. These loads, moreover, exert dynamic effects which are enormously increased if the track is not absolutely level or the ballast below is of uneven solidity. The weakest point in the stretch of track comes, of course, at the rail joints, where an attempt is made to restore the girder strength of the rail by clamping a pair of fish-plates or angle plates against the abutting ends. Never is it possible completely to restore the strength at this point, and should the nuts or the bolts work loose, as they constantly tend to, the strength of the joint is proportionately reduced; it sags under the load and each wheel, as it thunders by, drops into a hollow and strikes a terrific blow against the end of the second rail as it passes over.

But this is not all; for the expansion and contraction of the steel under changes of temperature set up heavy tensional stresses throughout the rail; and, moreover, there is an insidious action known as "creeping," in which the rail, because of its wave-like deformation under the load, is pushed and drawn forward against the holding power of the spikes and anti-creeping clips. There is also to be added the lateral stresses due to the side blows of the train, particularly when that curious

lateral swaying motion, known as "nosing," sets up, in which a massive locomotive, weighing frequently several hundred tons, sways from side to side, delivering heavy lateral thrusts against the head of the rail, tending to overturn it. And finally there are the severe abrading and crushing effects of the concentrated wheel-loads upon the head of the rail, due to the aforementioned pounding and to the heavy traction of the driving wheels and the retarding effect when the brakes are applied. In a word, the traffic is all the time endeavoring to crush the rail by compression, to tear it asunder by tension, to twist it out of shape by torsional twisting forces, or grind it away by severe friction.

To meet all the above attacks, therefore, the rail must be tough, hard, and moderately elastic, and it must possess these qualities so surely that the lives of millions of people flying along these two slight strips of steel must be so safe that accidents shall be only one to so many millions of the people transported.

In the early days of railroad history, and up to some 15 or 20 years ago, rails were rolled from Bessemer steel and the railroads called for a steel carrying about 0.40 per cent of carbon. High carbon means hardness and resistance to wear; but it carries with it a brittleness which leads to fracture. As a matter of fact, fractures, as rails grew heavier, began to occur with alarming frequency. An even more prolific cause of breakages was brittleness due to some extent to the

phosphorus in the Bessemer steel, which was liable to run as high as 0.10 per cent. Phosphorus, however, cannot be eliminated in the converter, and in answer to the demand of the railroads, and in their desire to produce a reliable rail, the manufacturers began to turn to the open-hearth process, in which the phosphorus content can be absolutely controlled. Thereby

A STEEL INGOT, MADE UNDER OLD STANDARD PRACTICE, SPLIT OPEN TO SHOW THE "PIPE" OR HOLLOW AT TOP OF INGOT. THIS SHOULD BE CROPPED OFF. OTHERWISE IT WILL BE ROLLED INTO THE RAIL, AND FAILING TO BE WELDED UP WILL BE APT TO RESULT IN A SPLIT RAIL. UP-TO-DATE PRACTICE HAS PRACTICALLY ELIMINATED THE PIPE.

they were able to get rid of the dangerous brittleness of the Bessemer rail; for, due to the reduction of the phosphorus to as low as 0.05 or less per cent, they were able to increase the carbon content and produce a rail that was at once tough and elastic, and therefore safe, and with sufficient hardness in the head to stand up to its work during a reasonably long life of service.

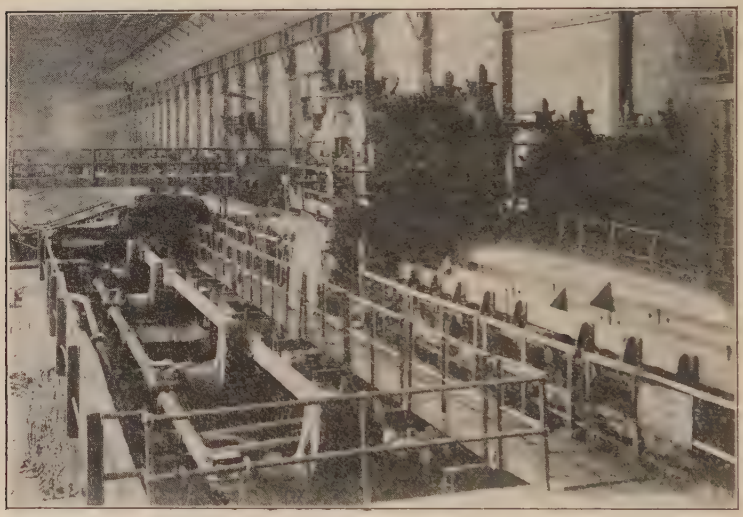
A modern hundred-pound rail, therefore, will carry

about 0.25 per cent of silicon, from 0.60 to 0.75 per cent of carbon, about 0.045 per cent of sulphur and a high content of from 0.70 to 0.90 per cent of manganese, this last element, if it be used with moderation, serving to give a tough steel.

We have seen in the preceding chapters that the chemical composition of the steel is determined during its treatment in the converter, the open-hearth furnace or the electric furnace, and that the question of its composition is an all-important one.

Now the cast-steel ingot might be called the raw material of the rail mill, and it will be understood that all the desired chemical constituents are already in the ingot. The rail mills make no change in this composition and they are concerned merely with shaping the ingot into the standard American pattern known as the T rail, with a heavy square head, a rather slight vertical web and a broad, flat, tapering base. But it should be noted that, although the rolling produces no chemical change, it does produce very marked physical changes, for the cast ingot is crystalline in structure but lacks homogeneity of crystalline structure, and therefore, possesses comparatively small tensile and torsional strength. The rolling serves to compact and elongate the crystals and thereby greatly increases the all-round strength of the steel. The rolling also increases the density and toughness of the steel, and in fact gives it a general increase in strength.

For the present brief description of rail rolling we have chosen the plant at Gary, Ind., which contains the largest rail mill in existence. The proportions are enormous, the main building being 1,000 feet long, with another building, containing the "soaking" pits for both the rail mill and the billet mill, which is 1,350



THE CONTINUOUS RAIL MILL AT GARY, 1000 FEET LONG, IN WHICH THE RAIL IS ROLLED DOWN FROM THE INGOT WITHOUT REHEATING. THIS IS THE UPPER END WHERE THE INGOT RECEIVES ITS FIRST ROLLING

feet long by 84 feet wide. So far as we know, this is the only electrically-driven mill which rolls rails direct from the ingot without reheating. The roll trains are driven by 6,600-volt induction motors, three of 6,000 horsepower, and three of 2,000 horsepower. The rolls and traveling tables extend continuously down the whole 1,000-foot length of this building. At the upper

end the white-hot ingots enter the first set of rolls and after 18 successive passes emerge at the lower end as finished rails. The rolling process is continuous, night and day, and to stand on the observation platform and watch the mighty operations is one of the sensations of our present-day, highly sensational industrial world. In every 24 hours this mill can turn out 4,000 tons of finished 100-pound rails.

At the Gary mill the ingot molds are carried on four-wheeled cars, four to each car. After the steel metal has cooled to the point of solidification the molds are lifted off by an overhead crane, and then each ingot is picked up and lowered into a soaking pit. This is a comparatively small furnace with a cast-iron, silica-brick-lined cover, which is heated by burning gas. Here the ingot remains for an hour and a half, more or less, according to the quality of the steel, and in these pits the workmen will tell you that the ingots "set"—that is to say, they become of uniform temperature throughout, so that there is no soft core of partly solidified metal at the center. The soaking pits at Gary can take four ingots per pit. In them, the temperature of the ingots is raised to the desired point for rolling. When an ingot is ready, the cover is removed, an arm from an overhead crane reaches down and with its steel fingers grips the ingot, lifts it out and sets it on a rolling table, which consists of rotating rolls set one beyond the other in the direction of the first four sets of ingot rolls. In these the

four-ton ingot is reduced to a "bloom," 14½ inches by 11½ inches, by 15 feet long. It then moves on to the three-high blooming mills, which consist of three rolls, each about 33 inches in diameter, placed vertically one above the other and journaled at each end in a pair of massive upright standards. The lowest roll rotates counter clockwise, the middle roll clockwise, and the topmost roll counter-clockwise. The vertical space between the rolls is regulated by massive screws set in the top of the housing. With a crash the white-hot bloom sweeps through the rolls on to a large vertically adjustable table. The table rises until it is level with the aperture between the middle and the top roll, the ingot being turned over through 90 degrees by means of levers operated from a distant platform; it stops, reverses its motion, and then comes back with a crash between the middle and upper roll. It is received on a table which is lowered and sends the mass through for its third pass, the bloom steadily growing smaller in section and increasing proportionately in length. Thus, in scarcely more time than it takes to tell it, the bloom has made nine passes and it is now one-quarter of its original section and proportionately longer. Next, it rushes down the mill on rapidly spinning rollers to the shears, which cut off its rough ends, containing impurities and also what there may be of any original "pipe." It is cut to the desired lengths and the pieces pass on to the first of the "roughing" rolls. The "pipe," it should be ex-

plained, is a central funnel-shaped cavity, which forms in the head of the ingot as it cools. The "pipe" usually contains segregated material (constituents of the steel that have separated out during the cooling) with oxide of iron, cinders, and other extraneous material. If the "pipe" were allowed to remain in the ingot, its surfaces

THE LOWER END OF THE GARY CONTINUOUS RAIL MILL, SHOWING THE FINISHED RAIL EMERGING FROM THE ROLLS. THE MILL CAN ROLL 4,000 TONS OF 100-POUND RAILS IN 24 HOURS

would fail to be welded together during the rolling, and an incipient longitudinal fracture would exist in the rail. In earlier years, before the danger was fully recognized, split rail ends, due to "pipe," were a frequent cause of derailment.

Hitherto the rolls have been true cylinders. From now on the successive rolls have deep grooves which,

in each successive set of rolls, correspond more and more to the shape of the finished rails. Three passes are made through the first "roughing" rolls, a single pass through the second "roughing" rolls, and another pass through the "dummy" rolls, by which time the rail is recognizable for what it is going to be. Finally, there are four passes through the finishing rolls during which the rail assumes its perfect finished shape. From the last finishing roll the rail, looking for all the world like a huge red snake, comes to rest beside three circular saws, which are set at distances corresponding to the 33-foot length of the rail plus several inches allowance for contraction during cooling.

Not only does the heat in the rail affect its length but it throws it out of line longitudinally, and if provision were not made to counteract this it would be badly curved in its length when it cooled down. The latter tendency is counteracted by passing the rail through a cambering machine, which bends it so that it is convex as to its upper face. The rail is then carried down a roller table and drawn laterally on to what is known as the cooling bed, where it cools down and the cambering disappears leaving the rail approximately straight.

Each rail is then conveyed to gag presses where it is cold-straightened. In the gag press the rail is placed upon two supports which are from 40 to 60 inches apart. Here any part of the rail that deviates from the straight is laid upon these supports and a

plunger comes down centrally between them to do the straightening. A skilled workman determines the amount to which the rail is to be bent, by placing between the plunger head and the rail a flat gagging iron, which is slightly tapered. This straightening is done on all four sides of the rail. After this the rails are finished off by chipping or grinding to remove burrs and the sawn ends are smoothed by filing. Then the rails go to the drilling machine, where three holes are drilled at each end for the insertion of the splice-bolts.

It should be mentioned here that during the rolling of the rails at the Gary shops there are no less than seven separate inspections, after the last of which they are loaded at the stock piles. From stock they are loaded on to the railroad cars by powerful magnets suspended from overhead cranes, weighed, and shipped to the customer.

CHAPTER IX

The Manufacture of Rods, Wire and Nails

Steel wire is drawn from what are known in the trade as "wire rods," and the magnitude of the industry may be judged from the fact that in the year 1923 our mills turned out a total of 3,075,892 tons of wire rods. This total was greater than that for steel rails, whose total output was 2,904,516.

Of all the metal products of human industry, wire is one of the earliest. There is evidence that it was known to the early Egyptians, and in the Kensington Museum, London, is a piece of wire which was made not less than 500 years B. C. The earliest specimens were mainly narrow strips of such metal as gold, silver, and copper, and were very different from the round wire that we know today. The production of wire by drawing down a rod to a smaller diameter by pulling it through a steel die, is also an art with a venerable history, the first record of its use occurring early in mediæval times.

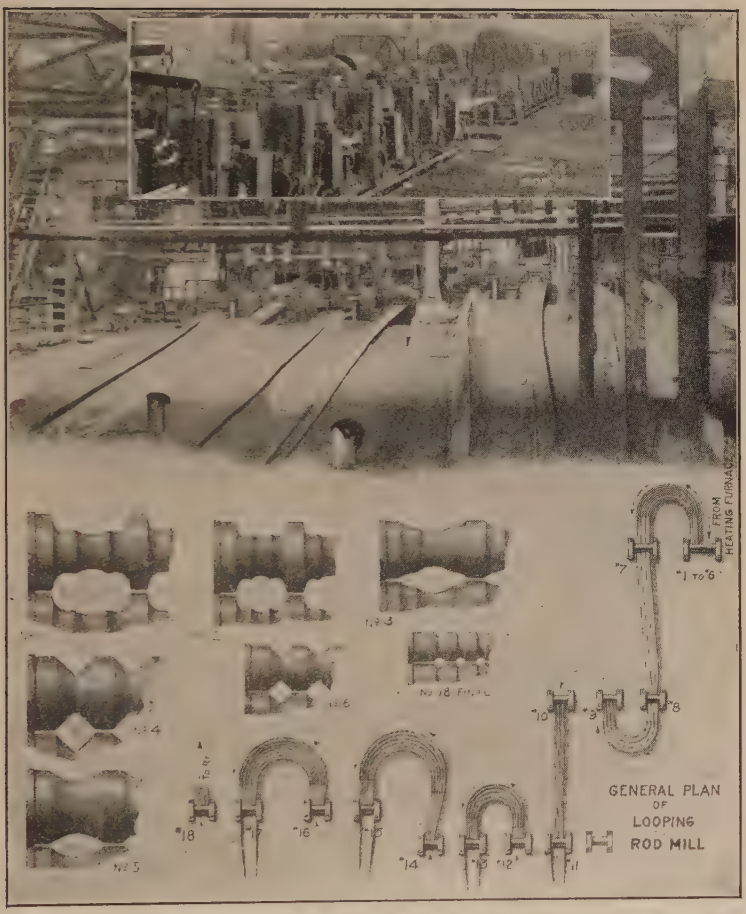
Originally, both wire and wire nails were made by hand from wrought iron, and their cost was high; it was only a question of time before steel, because of its low cost and great strength, became the standard material in this as well as in the other branches of the

metal industry. Today, practically the whole of the wire output is made from either Bessemer or open-hearth steel, the latter being specified where high physical properties are called for. As showing the increase in strength of steel over iron wire we mention that, while good black-iron wire would show an average ultimate tensile strength of 25 tons to the square inch, Bessemer steel wire will stand an average stress of 40 tons, and open-hearth steel wire an average of 60 tons to the square inch. These figures are approximate; they will vary according to the treatment the wire receives during its manufacture. Of the special grades, a high-carbon open-hearth steel wire will carry about 80 tons, crucible cast-iron wire about 100 tons, and the best cast steel, or "plow" steel wire 120 tons to the square inch; while certain qualities of cast-steel wire, of a particular composition and calling for very elaborate working, have shown an ultimate breaking strength of 150 to 170 tons to the square inch.

The process of wire drawing serves greatly to improve the strength, and the smaller the size to which the wire is drawn the greater is its relative breaking strength. We have all heard of the strength of piano wire, whose average maximum ranges from 225 pounds for a single music wire .029 inch in diameter to 650 pounds breaking strength for a single wire .052 inch in diameter. Reduced to the square-inch unit, the ultimate strength would be from 307,000 to 340,000 pounds. An analysis of the following specimen of

steel music wire will be of interest: carbon 0.83, manganese 0.59, silicon 0.143, sulphur 0.009, copper 0.030, and phosphorus .010. Piano wire made under these specifications runs from 200,000 pounds per square inch for wire 0.191 inch in diameter to 350,000 pounds per square inch for wire 0.093 inch in diameter.

As the ingot is the raw material for billet-making, so the billet is the raw material for wire rods and wire. Therefore, we will commence our story at the billet stock yard where the steel is stored conveniently to the heating furnaces of the rod mill. It should be mentioned here that the bulk of the wire and wire nails of commerce are manufactured from Bessemer billets, and that open-hearth billets are worked up into rods for the manufacture of chain, for special grades of wire and for various finished products in which high tensile strength is called for. Let us go to the upper end of the rod mill where we shall find several billet continuous-heating furnaces. These furnaces are built with a floor inclined upwardly in the direction of the mill and they are gas-fired. The billets which vary in size, but in the mill inspected measured 4 by 4 inches in section and 36 inches to 48 inches in length, are fed transversely into the furnace side by side, and are pushed slowly by a hydraulic machine over water-cooled skids, so that by the time they reach the upper end they have been heated to the proper temperature for rolling. One by one they pass out through the door



Above: LOOPING ROD MILL, WITH INSERT SHOWING CONTINUOUS ROD MILL. *Below (left)* SHOWS SHAPE OF GROOVES IN ROLLS FOR FIRST PASSES OF BILLET. *Right:* GENERAL LAYOUT OF A LOOPING MILL

and fall upon a conveyor upon which they are carried down into the rod mill.

The rod mills in their modern forms are of two types, one the looping mill and the other the continuous mill. In some works these two types are combined in one mill. These mills consist of a series of pairs of rolls which are arranged side by side in the looping mill and parallel to each other in the continuous mill. There are 13 pairs of rolls in the looping mill which we have chosen for illustration, and by the time the billet has made the sixth pass (the last pass in the roughing train) it has been reduced from its original dimensions of 4 inches by 4 inches by 48 inches to a one-inch square section. In the lower half of our full-page drawing we show sections of the first six passes through these rolls and of the finished rod after the eighteenth pass. It will be noticed that the rolls are grooved and that the opening between the upper and lower grooves varies both in its contour and its cross-sectional area. At each pass the billet is reduced in area and proportionately increased in length. Hence, the speed of the successive rolls is increased to compensate for the increasing elongation. By changing the shapes of the grooves in the successive pairs of rolls, making them alternately square and oval, a more thorough working of the metal is obtained and its qualities are proportionately improved.

After pass No. 6 the rods pass through the successive rolls in alternating directions, describing long loops

between each pair as shown in the upper half of the accompanying illustration. To guide the rods into the proper rolls, workmen stand between each set, and as the rod issues from one set of rolls it is seized with a pair of tongs, bent around through a half circle and fed to the next "pass." When a rod mill is running in full blast, it presents a most curious and sensational sight; for owing to its decrease in section and increase in length as the rod passes through the successive rolls, the speed of the rods and the length of the loops increases; and by the time the rod issues from its last or eighteenth pass, it is traveling at a speed of about 1,400 feet per minute, or 16 miles an hour.

It will be understood that, as this variation from square to oval and oval to square is carried on, not only in the six roughing passes but in the other 12 passes of the looping mill, the metal is subjected to an enormous amount of mechanical working, and its strength is thereby greatly improved, so that when the final round rod 13/64 of an inch in diameter issues from the eighteenth pass, as it is called, it is already of high tensile quality. As the rods leave the last pair of rolls, they are run through pipe guides to reels, on which they are wound up into a convenient coil for further handling. From the reel the wire falls on to a conveyor and is carried to the wire mill. The insert illustration shows a continuous rod mill in which the heated billet passes through a series of rolls in a continuous straight line to form the rod. As in the case

of the looping mill, the finished rods are conveyed to reels where they are coiled into bundles.

In the wire mill the first thing done with the wire rods is to thoroughly clean them of scale, oil, dirt, etc. This is done by immersing the coils in wooden vats containing a weak solution of sulphuric acid. The coils of wire are removed from the acid vats and hung upon a rack, where they are thoroughly washed with water and left long enough to permit of a slight oxidation on the surface; the object of this rust coating being to lubricate the wire ready for the process of drawing it down. Next, the coils are placed in a bath of lime to neutralize any further effects of the acid, to prevent oxidation, and also to obtain a slight coating of lime, which acts as a lubricant to the wire as it passes through the dies. The wire is then dried out thoroughly in the "bakers." Up to this point in our description, the product is known under the technical name of "rods," and it is only after it has been drawn down in the dies that it is known commercially as "wire." Wire-drawing is of ancient origin, for about the year 1365 there is a record that Rudolph of Nuremberg produced wire by drawing metal bars through tapered holes in a die. There are descriptions also of wire-drawing machinery which were published in the sixteenth century. Thereafter it gradually took the place of the earlier method of hammering out the wire by hand, which dates back to some 800 years before the Christian era.

Wire-drawing not only permits the production of a much smaller wire than could be produced under the hammer or in the rolls, but the process of drawing it down cold increases its tensile strength to a truly remarkable degree, although it also renders it less ductile and more brittle. The wire-drawing machine consists of a solidly constructed bench on which is mounted on a vertical axis a strong cast-iron drum, power driven, on to which the wire is wound as it is drawn through the die. The die-plates are stout blocks made of the very best tool steel or of chilled cast iron, which are perforated with holes carefully gauged to the exact desired size of the wire. The holes have considerable taper, the wire of course, entering at the larger end. The coil of wire which is to be drawn is placed on a reel, and the loose end having been pointed or swaged down it is passed through the die-plate and attached to the drum, which then proceeds to wind up the wire until the whole coil has been drawn down. Since the wire-drawing is done cold, it can be well understood that, with a hundred or more of these machines running at the same time it requires very powerful motive power to drive the mill.

After drawing it is necessary to remove the strains in the wire by careful annealing, and it is therefore taken to the annealing room where it is loaded into large annealing pots. After a pot is filled it is carefully sealed to exclude the air, and the wire is then exposed to a steady heat for from eight to nine hours.

Of the whole product, part is now ready for the open market without any further treatment, part of it is sent to the galvanizing room to be galvanized, and a large proportion goes to other mills to be made up into wire nails, barbed wire, wire fencing, etc.

In a modern nail mill one will find from 150 to 300 separate machines, each of which is capable of turning out from 150 to 350 finished nails per minute. It may truly be said that a modern nail machine is one of the most striking examples of the enormous increase in capacity which has resulted from the introduction of labor-saving machinery.

In front of each machine is a reel upon which a coil of drawn wire is placed. One end of the wire is led into the machine and as the power is thrown on one sees the wire disappear through a small hole in a vertical casting; while to the accompaniment of a rapid succession of blows that sounds like a machine gun, a stream of finished wire nails begins to pour out of the opposite side of the machine into small iron boxes placed to receive them. The wire, as led from the coil, first passes between two pairs of horizontal grooved wheels, which are firmly pressed together to give the required tension to the wire as it is drawn into the machine after each finished nail has been formed and cut off. The head is formed up by a very powerful cam-operated member, which strikes a hammer-like blow. The nail is pointed by the action of a pair of dies with V-shaped cutting edges. As each nail is

finished the wire is gripped and enough of it pushed forward to make another nail. The 3-D fine nails are turned out at the rate of 350 per minute, and the large 60-D nails at the rate of 150 per minute.

The boxes of finished nails are then taken to big revolving iron cylinders known as tumblers, where they are rolled over and over, the nails being thrown against the side of the cylinders and against each other, thereby receiving that high polish which characterizes the finished product. A certain amount of sawdust is inserted in the tumbler to clean the nails thoroughly of grease and dirt.

CHAPTER X

Rolling Shapes for Bridges and Buildings

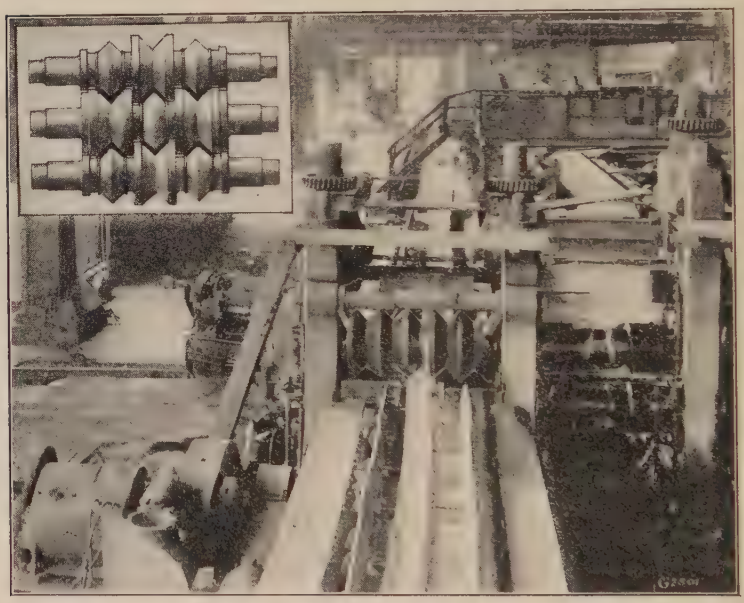
The American steel bridge and the steel-masonry building are two forms of construction which are recognized, the latter as having originated and been developed in America, and the former as possessing certain outstanding characteristics which have caused it to be recognized as a distinctively American type. Particularly of bridge building may it be said, that it is to the improved methods of manufacture and shop management that the rapidity and low cost of construction and erection of American bridges was due during the greatest era in the history of bridge construction in America. So also in that essentially American structure, the skeleton steel building, we have developed, under the urge of necessity, a type which is distinctively our own and bids fair in these later days to become the established type in such cities of the world as are obliged by topographical and other conditions to mass a large working population upon a limited area of ground.

Although the distinctive age of American bridge-building, above referred to, has passed and the pressing necessities, at least for bridges of the larger type, have been met, the tall office building and the far-spreading and many-storied factory have continued to grow at an

ever increasing rate. To meet that growth there has been a corresponding increase in the capacity of the shops which turn out that kind of steel building material which is known by the generic name of "shapes," under which are included angle-irons, T-irons, I-beams, Z-bars, channel irons, etc. It should be noted that it is customary to speak of "heavy" and "light" structural shapes, the former including all beams, angles, etc., having one leg or web of three inches and over and a thickness of one-quarter inch and over, which are rolled for structural or fabricating purposes; the "light" shapes and small angles being such as are rolled for the manufacture of bedsteads, agricultural implements, fences, or for other fabrication having a smaller section than that above given. It will readily be understood that in view of the growth of the country both in population and industrial development, the production of heavy and light structural shapes runs to large figures. In 1914 the total output was 2,031,124 tons. Due to the impetus of the war, the total rose in 1916 to 3,029,-964 tons. It dropped in 1921 to 1,272,624; but in 1923, after a remarkably rapid increase, structural shapes showed an output of 3,405,197 tons, the greatest in the history of this industry. It is needless to say that practically the whole of this material was rolled from steel, 1,448 tons only being rolled from iron.

In its broad outlines the production of "shapes" is similar to that of any other rolled-steel product. The steel is tapped from the furnace to the pouring ladle,

cast into ingots and, after due heating in the soaking pits, is rolled down into blooms, billets and the particular finished shapes desired. The shapes, plates, etc., for bridge work are rolled entirely from open-hearth steel, three grades being produced, namely, "rivet,"



ROLLING STEEL ANGLES. NOTE SHAPE OF THREE-HIGH ROLLS IN INSERT

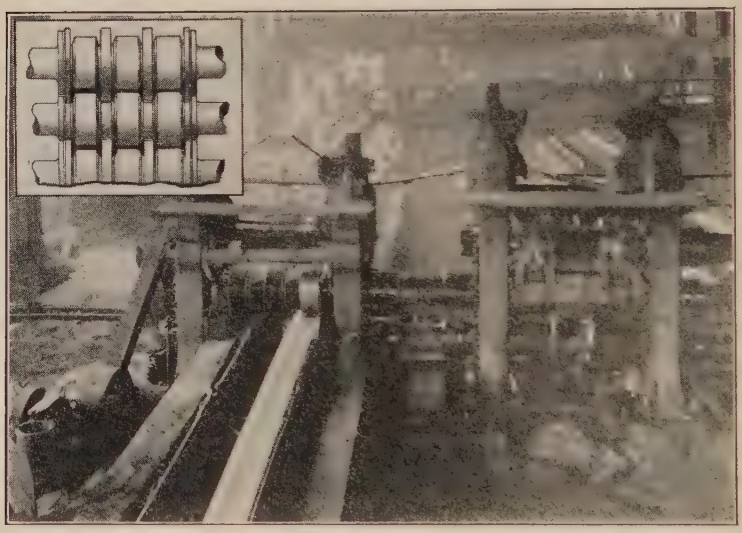
"soft" and "medium." Rivet steel has an ultimate strength of from 50,000 to 60,000 pounds; soft steel from 52,000 to 62,000 pounds; medium steel runs from 60,000 to 70,000 pounds. The elastic limit is about 50 per cent of the ultimate strength and test pieces of steel must be capable of being bent over on themselves through an angle of about 180 degrees without fracture.

Of late years bridge engineers have been calling for special grades of alloy steel, particularly for I-bars, and in this case the ultimate strength will run up from about 80,000 pounds to 100,000 pounds per square inch with an elastic limit of 50,000 pounds.

The visitor to any complete bridge manufacturing plant will be taken first to the stock yard in which the raw materials are assembled ready for the open-hearth furnace. Here he will find iron ore, scrapped steel, such as junk, crop ends, punchings and general scrap from the construction and machine shops. Also in some works he will find a considerable stock of pig iron in the stock yard. In other works, and those the most modern, the pig for the open-hearth furnace will be brought direct from the blast furnaces. Before the pig is run in, a certain proportion of cold scrap, etc., has been placed in the furnace. The work of refining is carried on as described in Chapter VI.

The blooms and slabs from which the shapes are rolled are themselves rolled down to size from ingots of suitable size. An 8 by 8-inch bloom will be rolled from an ingot about 20 inches square and a slab of, say, 7½ by 4¼ inches, will be rolled down from a 23 by 19-inch ingot. Generally, the ingots are rolled down into blooms in mills of the reversing type. The ingot, raised to the desired rolling heat in soaking pits, passes between the rolls, is received at the rear side, and, the rolls being then reversed, the ingot makes a return pass. What are known as pick-up fingers serve

to turn the ingot over through 90 degrees if so desired between certain passes. After the ingot has been brought down by, say, from a dozen to fifteen passes, to a bloom of the required size, the bloom is transferred to a shear where it is cut into the length desired for rolling into the particular shape required.



ROLLING 12-INCH CHANNELS. THE FINISHING PASS AT FINISHING ROLLS. THE INSERT SHOWS THREE-HIGH ROLLS FOR ROLLING I-BEAMS

The rolling of the shapes is frequently done on a continuous-type mill of eight consecutive stands of rolls. In a well-appointed mill about one-half of the steel is rolled from the ingot to the finished shape without any intermediate reheating. The mills usually have six stands of rolls arranged consecutively in train. As a rule, the roughing and semi-finishing are done in sets

of three-high rolls while the finishing is done between two-high rolls.

After the shapes have passed through the finishing mill, they are transferred by roller tables and brought to circular saws which cut them to the desired length. Similarly to the rails, the shapes, as finished, are usually out of alinement and have to be straightened before they are shipped to the customer. This straightening is done in a gag press similar in its action to the straightening press described in the chapter on the manufacture of steel rails.

The art of bridge construction consists, so far as shop fabrication is concerned, in building up large and massive members out of a multitude of relatively small shapes as they are assembled in the stock yards of the bridge works. In the receiving yard at the Gary Bridge Works, which is 285 feet in width and 800 feet in length, there has been assembled, at times, in the way of plates, bars, angles, I-beams, etc., as high as 40,000 tons of material. Since in bridge-building the weights run to high figures, it can be understood that the construction shops are so laid out as to render the operations as continuous as possible with a minimum of handling and transportation.

The first operation is to lay out the work by means of wooden templates in which the exact position of every rivet, angle, gusset, etc., is marked. As a matter of fact, the building up of the bridge material into those huge posts and tension members which look so

DRILLING, REAMING, AND RIVETING UP A 35-TON MEMBER FOR A LARGE BRIDGE

awe-inspiring in a huge cantilever or suspension bridge, is a simple one, the chief requisite being great care and accuracy. The plates and shapes are sawn or sheared to exact length and, where it is called for, the sides and ends are planed and faced down. Holes for the larger pins are first punched and then bored to exact dimensions; but the small holes for bolts and rivets are punched by means of highly developed machinery driven by electric power. It should be mentioned, however, that there is a tendency to abolish the punching of rivet holes, because of the undesirable stress set up in the adjoining material, and substitute everywhere straight drilling.

The punching and drilling being completed, the separate pieces are assembled and bolted together, care being taken that the rivet holes are properly registered, reaming being resorted to, if necessary. The work is then riveted up by hydraulic and pneumatic riveters.

The accompanying drawing represents the riveting up of a 35-ton member for a bridge of large dimensions. It shows two tools which have done great service in bridge construction; namely, an electrically driven portable drill and a portable pneumatic riveter. Of late years there has been a great development in the size and power of bridge-building tools and in the Gary shops there are hydraulic riveters capable of exerting a pressure of 100 tons on a hot rivet head.

After the bridge members have been completed at the shops they are shipped out to the site where the bridge

is to be erected; and it can readily be understood that the speed with which the erection proceeds depends very much upon the extreme accuracy with which the work has been done in the fabricating shops, which may be located several hundreds or thousands of miles away from the bridge site.

Twenty-five or thirty years ago, American bridges of 500-foot span and less were almost universally of what

HEAVY PLATE GIRDER FOR BRIDGE ON MAIN LINE OF NEW YORK CENTRAL RAILROAD. LENGTH 121½ FEET; DEPTH 11 FEET 5 INCHES; WEIGHT 130 TONS

is known as the I-bar type; that is to say, while the compression members were of built-up box or rectangular cross-section, the tension members almost invariably consisted of I-bars; that is flat bars provided with an eye at each end for engagement with a common pin in the assembly of members at a panel point. The I-bar type provided a bridge that was easy and quick in fabrication and lent itself to rapid erection. In those days, moreover, even in bridges of 100-foot span and less the open triangulated truss bridge was preferred. Of late years, however, there has been a marked tend-

ency towards riveted plate bridges. The field of the plate girder which formerly was restricted to very short spans, has been extended until today we find that 100-foot-span plate girders are common and not a few of this type have exceeded 100 feet. The longest plate steel girder built at the Gary works measured 115 feet 6 inches. This type has found its most extensive use among the railroads.

CHAPTER XI

The Manufacture of Steel Pipe

Among the commodities which man has fabricated for his own use but few have a more ancient history than that of tubing, or pipe, which, from time immemorial has been made in a more or less crude form of such materials as the slow progress of the arts has made available. The stone aqueduct, that most ancient device for the conveyance of water through a closed conduit, might almost be said to head the list in point of antiquity—at least, when it was built in smaller sizes. The ancients, we know, formed pipe out of various metals—copper, bronze, etc., and those great engineers the Romans made elaborate use of lead piping. It was inevitable that, with the development of iron manufacture this excellent material should be used increasingly for pipe. In the early days of this Republic, when iron works were few and widely scattered, we know that trees were cut down, bored and wedged together, to distribute the water supply of the more important towns of that period; and the old wooden pipes are being dug up occasionally as we build subways or sink foundations.

The introduction of artificial gas for lighting purposes, the demand for reliable tubes for steam boilers,

to say nothing of the call for pipe of lasting quality for the large municipal water systems—all these conditions led naturally to the endeavor to produce pipe from wrought iron, and we are told that the first furnace for making butt-welded pipe in this country was built about 1832 in the cellar of a shop at Third and Walnut Streets, Philadelphia. From that small beginning there has grown up the present huge industry, whose total output in the United States of all kinds of tubing and piping reached in 1923 a total of 3,351,-023 tons, the largest in the history of this particular branch of the steel industry.

Up to the period of the early 'eighties of the nineteenth century, outside of such special piping as was made of brass and copper, tubular products were made entirely from wrought iron; for it was believed that steel did not offer the suitable welding and other qualities for first-class pipe. During the 'eighties, however, there was considerable experimental effort directed toward the utilization of steel for the manufacture of welded pipe and boiler tubes; although these early efforts were met by the prejudices and opposition which seem to be inevitable when any radical change is introduced in a long-established industry. In proof of this we quote from a paper read before the Engineers' Society of Western Pennsylvania on June 17, 1888, by Mr. Thomas J. Bray of the National Tube Company: "Toward the latter part of August about 30 tons of steel were made and rolled into skelp, and delivered

at the tube works as a trial lot, to be made up into pipe. . . . The welders at the furnace said at the outset that it would not do; that it would not stand firm; and by reason of their prejudice against steel they subjected it to abuse by severe overheating; yet strange to say, every piece of that lot made a sound, salable pipe, the welders remarking that it was the best material to weld they had ever handled."

In the course of time, tubing came to be made out of Bessemer steel, and in later years open-hearth steel was utilized for the best grades of pipe. The brilliant success attending the use of steel in pipe manufacture is proved by the fact that, whereas in 1890 probably less than five per cent of the wrought tubular products made in this country was of steel, in less than 30 years the situation had fully reversed itself; so that today well over 90 per cent of the wrought tubular products in this country is of steel.

Steel pipe is made from long strips of plate steel by curving them into circular or tubular form, and then welding the adjoining longitudinal edges by what is known either as a butt-weld or a lap-weld.

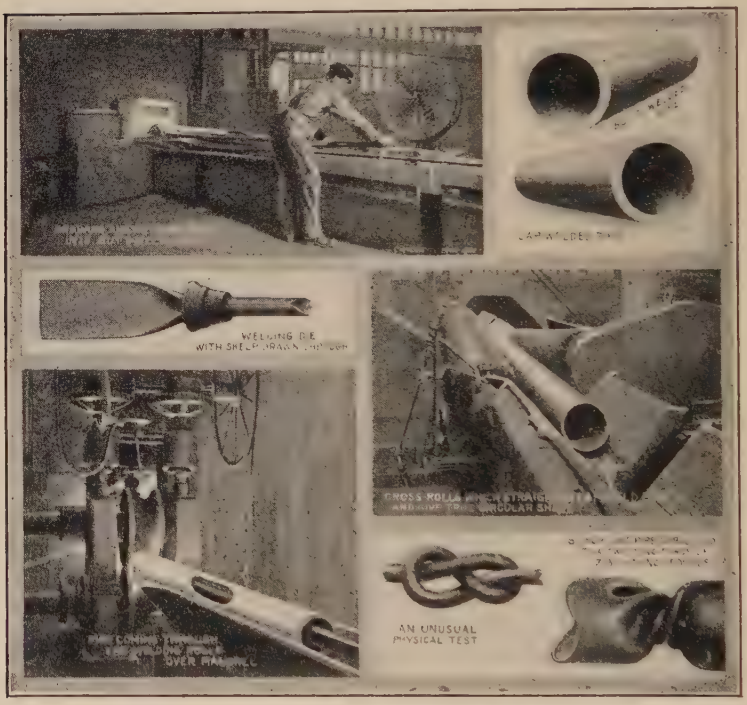
Our illustrations show the outstanding steps in this process. The manufacture of the steel for steel pipe is broadly similar to that in other branches of the steel-making industry, as already described in previous chapters. The charge in the blast furnace, so far as the ore for tubular products is concerned, is made up of various ores selected and mixed so as to produce the steel

required. The ingots are heated in the soaking pits and rolled down into blooms and slabs, and finally into those long, comparatively thin and narrow strips of steel plate which are known as skelp. The blooms are heated and rolled down to the proper weight and thickness for the size of pipe required. In the more modern plants the rolling mills are of the continuous type, the blooms entering at one end of the mill and traveling through several sets of rolls continuously in one direction, until they emerge at the lower end as finished skelp.

Butt-welding

The skelp for butt-welding is charged into a long furnace and raised to the welding temperature. When it has reached the proper heat, one end is grasped by a long-handled tongs, and pulled through a die or bell of the form shown in one of our engravings. The end of the bell next the furnace is in the form of a stout, flat plate, the edges of which gradually curve up to form a circular opening slightly larger than the pipe which is to be finished. After they have gripped the end of the skelp, the handles of the tongs are connected to an endless chain which travels in the middle of the draw-bench. This chain is in the form of a long continuous belt, which travels away from the furnace on the top of the bench, returning beneath it, and it is driven by motors of great power. The moment the tongs are linked to the chain they and the skelp are drawn for-

ward, and as the skelp passes through the die it is formed up into a circular tube, with its two edges abutting. For some sizes of pipe the skelp is drawn through two bells at one heat, the last pass being made



THESE ILLUSTRATIONS SHOW HOW THE FLAT STRIPS OF STEEL ("SKELP") ARE FORMED UP AND WELDED INTO LENGTHS OF PIPE. THE DIFFERENCE BETWEEN THE METHODS OF BUTT AND LAP WELDING IS SHOWN IN THE TOP RIGHT-HAND DRAWING

through a bell which is slightly smaller than the other. The width of the skelp is slightly greater than the inside circumference of the bell, so that the edges are forced to abut squarely against each other, and are

pressed together into a sound weld. For pipe of extra strength the skelp is drawn successively through bells of decreasing size and is reheated between the draws, so that the seam may be thoroughly welded.

After welding the pipe passes through the sizing rolls where it is slightly reduced in diameter and elongated. From the sizing rolls it is then conveyed over a transfer table to other rolls, in which it is slightly reduced and elongated and rolled to its finished size and circular contour. Any heavy mill scale or welding scale is removed by this rolling, leaving the pipe walls smooth and clean.

The pipe leaves the last span of rolls at a high temperature, and it is cooled by passing it slowly over a table. After it is cooled sufficiently, it is passed through a set of cross-rolls, which serve to give added smoothness to the pipe surface. These cross-rolls are somewhat larger in diameter at the ends than at the center, the surface being slightly curved in a longitudinal direction. Their axes are also somewhat inclined to teach other, with the result that, as the pipe is drawn through the rolls, its whole surface is in contact with them and receives a high finish. The butt-welded pipe is then washed to remove the loosened scale and any foreign matter, and some sizes have the loose scale blown out by a blast of compressed air. The ends of the pipe are cut off, to remove the portions that have been bruised by the jaws of the welding tongs, and the pipe is then threaded and a coupling is screwed on one

end. Finally, the pipe is tested by hydraulic pressure, which in butt-welded pipe varies from 700 to 800 pounds to the square inch.

Lap-welded Pipe

Although pipe, in sizes of from 1¼ to 3 inches, inclusive, may be made either by the butt-welding or lap-welding process, practically all pipe in these smaller sizes is made by the butt-weld process, while pipe of from 3 inches up to 30 inches, if that size be required, is made by the lap-weld process, which is so named because, instead of butting the edges together, they are overlapped and welded when in this position. The difference between the two is clearly shown in the accompanying sketch.

The first step in making lap-welded pipe is to bevel the edges of the pipe to form the lap. When the skelp has been heated to a suitable temperature for bending, it is pushed out of the furnace into a set of two-high scarfing rolls, which bevel the edges of the skelp in such a way that when they overlap and are welded there will be no undesirable thickness there. The scarfing rolls are formed with a beveled collar at one end, and they are so set in the housing that the bevel collar of one roll is to the left and the bevel collar of the other roll is to the right. By this arrangement the scarf, as the skelp comes from the rolls, is on the upper side at one edge of the skelp and on the lower side at the other edge; with the result that, when the

skelp is bent into circular form, the two scarfs will overlap as shown in the little sketch above referred to.

The skelp is then conveyed over a roller table to the bending or draw-bench. Here the forward end of it is gripped, as in the case of butt-welding, by the jaws of a pair of heavy tongs which are themselves attached to the endless chain of the draw-bench. The skelp is now pulled forward into a bending die, which forms it into circular shape with the edges overlapping. The action of this die is similar to that used in butt-welding, as above described.

Skelp for pipe over 12 inches in diameter is formed up in a three-roll bending machine, in which two rolls are placed adjoining and the third above but between them. The partially formed tube is then rolled down an inclined transfer table and conveyed, with several others, into the welding furnace. When the tube has been heated evenly throughout to the welding temperature, it is pushed out through the back of the furnace into the welding rolls.

The welding rolls are two-high, and each is accurately turned to a semi-circular contour, so that the opening between the rolls is circular and of the correct diameter to correspond with the outside diameter of the finished pipe. Between the rolls and carried on the end of a long stout bar or rod is a ball or mandrel, which is shaped somewhat like the head of a revolver bullet. Now it will be seen that, since the annular space between the mandrel and the surface of the rolls is

about equal to the thickness of the pipe, when the tube, with its overlapping edges at the top, passes between the rolls, the pressure set up between the bottom surface of the top roll and the upper surface of the mandrel will press the overlapping edges of the pipe together with great force and effect a sound weld.

The mandrel is then removed from the pipe and the latter is rolled on to a transfer table. If the weld is not quite satisfactory, the tube is returned to the welding furnace and again passed through the welding rolls. The next step is to pass the tube, which is still white-hot, through a set of sizing rolls, which are similar in shape to the welding rolls and serve to reduce the pipe to the required external diameter. It is customary to give the tube three passes between these rolls. The tube is then carried on by live rollers into the cross-rolls, which are similar to those described in butt-welding, and here the weld is strengthened and its surface is thoroughly rounded off.

The welded pipe is now transferred slowly (so that it may have time to cool) to the cold-saw, where the irregular ends are cropped. In the larger pipes the ends are removed in a rotary-type shear by means of three rotating disks, which cut the pipe.

The last step is to inspect the pipe, weigh and measure it. After this is done, in the case of the larger pipes, they are transferred to the threading shop. Here, after threading, a coupling or nipple is screwed on one

end and the pipe is ready for delivery. It should be mentioned that the larger pipes, like the butt-welded pipes, are subjected to hydrostatic pressure, which they must stand without leaking. The pressure used in the test depends, of course, on the size of the tube and service to which it is to be put. For standard-weight pipe the test is made at from 600 to 1,000 pounds per square inch, and extra strong pipe is subjected to from 700 to 2,500 pounds per square inch. The pipe is then taken to the shipping department.

CHAPTER XII

The Manufacture of Seamless Steel Tubes

From the early days of steel pipe or tube manufacturing, the makers have realized the advantages which would be secured if they could make tubing without the longitudinal seam which characterizes the lap and butt-welded piping described in our last chapter. The earliest recorded efforts in this direction were made when Hanson took out an English patent for the making of seamless tubes in 1837. Under this method the steel was squeezed through a small orifice around a punch. Then came a modified method patented in England in 1867, and another patented in 1882, the latter by Elliot. Elliot, according to his specification, forced melted steel hydraulically through an annular orifice, with the object of securing a tube in which the fibres were arranged helically. Another early process was that of "cupping," in which a cup was pressed from a flat disk and gradually elongated into a tube by passing it through a series of reducing dies.

Many of our readers will be interested to know that the popularity of bicycle-riding a generation ago gave a great impulse to the manufacture of seamless steel tubes. The tubes were drawn cold from billets which were prepared and partly finished into tubes in Eng-

land and Sweden. Finally, the great demand for high-class seamless tubes for naval and marine boilers and for locomotives led to the development of the methods of making "Shelby" seamless steel tubes, as illustrated and described in the present article.

Forming Blooms into Billets

What might be called the raw material for the manufacture of seamless steel tubing consists of blooms, varying from 6 to 10 inches in section and about 11 feet long, and weighing from 1,300 to 3,750 pounds. The blooms are picked up one by one by an electrical charging machine and placed in a special heating furnace. Here, when the proper temperature for rolling has been reached, the bloom is taken from the furnace, placed on a small electric buggy, and transferred to the "rolling table" of the bar mill, where in a series of rolls it is changed from a square bloom into a solid round bar, smaller in diameter but of greater length. Some of the bars thus formed are as much as 8 inches in diameter, while others are as small as 3 inches. While they are still at rolling heat, the bars are cut to different weights according to the length and thickness desired in the finished tube, and, while still hot, they are centered. After they have cooled they are sent to the piercing mill. Here, the first step is to make an indentation in the center of one end of the billet by means of a punch. The cavity thus formed is about one inch deep and it serves to insure the proper start-

ing of the hot billet in the piercing operation, and also insures an equal displacement of metal from the center to the circumference of the billet.

Piercing the Billet

The next step is to place the centered billets in a special heating furnace, the bottom of which is inclined. The billets are fed into the upper end, from which they roll by gravity to the lower end, where the temperature is such as to render the steel soft and semi-plastic.

The solid billet, which is almost white-hot, is pushed forward until it is caught by the rotating rolls of the piercing machine which forces it over the piercing point of a mandrel. The mandrel is a piece of hard steel, shaped something like the projectile of a heavy gun, which is carried at the end of a rod and is thereby held exactly in the correct position between the two heavy rotating rolls, as shown in one of our accompanying illustrations. These rolls are inclined slightly away from the point at which the piercing takes place, and this inclination coupled with their rotation in the same clockwise direction, as shown in the small insert illustration, serves to draw the solid billet forward over the piercing point of the mandrel. The effect of this is to cause the metal of the billet to flow past the mandrel and form the billet into a heavy solid tube. This operation requires enormous force, the degree of which is hardly suspected by anyone who witnesses the operation. The piercing machine is of such power that the

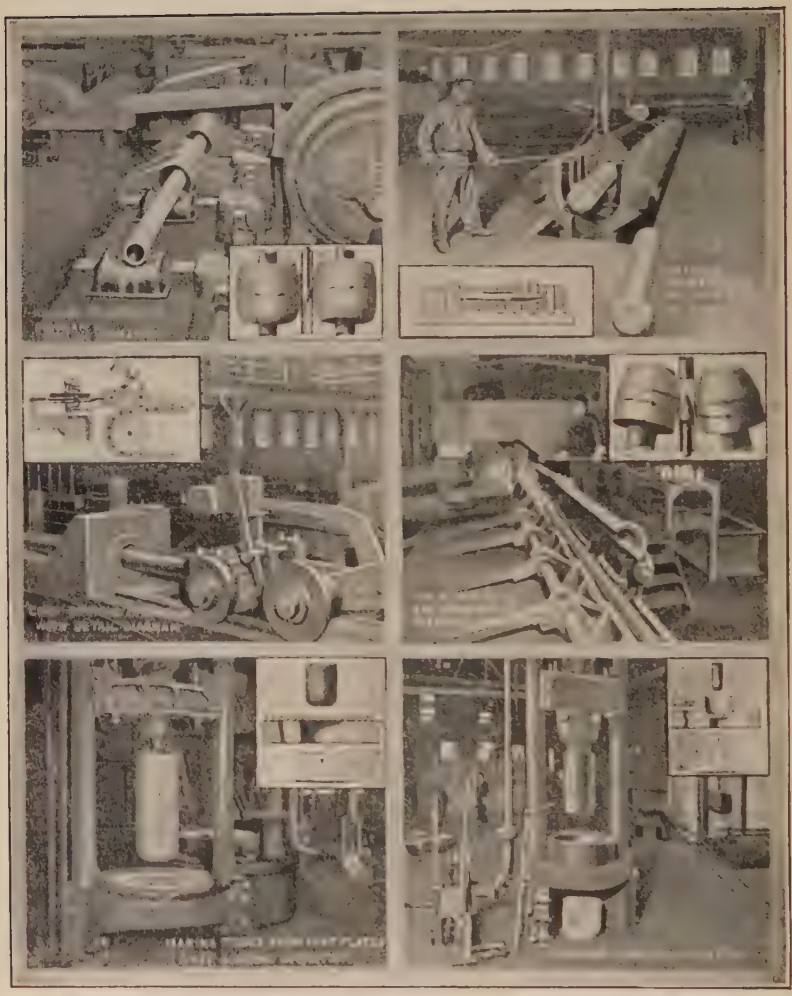
solid metal of the billet is transformed into a tube apparently with the same ease with which a lump of dough is manipulated into shape by a pastry cook.

Rolling the Pierced Billet to Size

The pierced billet comes out of this operation as a rather rough, thick-walled, seamless tube. Although it is rough as to finish, it is without seam or weld, the round bar of steel having been pierced through its whole length much as a potter would force a pointed rod through a cylindrical mass of moist clay. After its passage through the mill, it is rather short and its walls are of considerable thickness, and the next step is to reduce the thickness and increase the length and so form the desired size of tube. This is done by passing the pierced tube through adjustable half-round rolls between which is a mandrel held in place by a long steel bar just at the point where the thickness of the wall of the tube and its diameter are to be reduced. As it passes through this rolling mill, it is converted into a much longer tube with walls of uniform thickness, and it carries a fairly smooth finish.

The Reeling Machine

The next step is to pass the tube, which is still at a suitable working temperature, through what is known as the reeling machine. This is another form of rolling machine consisting of two heavy rolls of special design set with their axes askew, and these rolls are capable



VARIOUS STEPS IN THE MANUFACTURE OF SEAMLESS STEEL TUBING

of adjustment to a thousandth of an inch. One of the diagrams shows the nature of these rolls, their position, and their relation to the mandrel and the tube which passes between them. In this operation any mill-scale is removed; the tubes are given a smooth, burnished surface; and the outside diameter of the tube is brought closer to its final finished diameter.

In the finishing process the tubes are taken from the reeling machine and passed through the sizing or finishing rolls which give them the exact outside diameter.

The Cold-Drawn Process

The processes above described are known as hot-finishing, but a large amount of seamless tubing is made by what is known as the cold-drawn process. The first step in this is to point the end of the tube by swaging it down under a power hammer. The tubes are then cleaned and freed from mill-scale by pickling them in a hot acid bath. The cold-drawing apparatus consists of a very heavily built, horizontal, steel draw-bench, in the center of which is firmly positioned a hard die through which the tube is to be drawn down. In front of the die there is a heavy endless chain which travels along the top of the draw bench and in a direction away from the die, for a distance of 15 to 40 feet, and then passes over a sprocket which is power-driven. The endless chain returns underneath the draw bench.

The hot-rolled tube, which is now perfectly cold, is

inserted in the die with its pointed end projecting toward the endless chain. A mandrel is then slipped into the tube from its rear end until it lies in the proper position within the die. Then an operator seizes the pointed projecting end of the tube by very massive tongs, which are hooked to the endless traveling chain above described, and by this means the tube is drawn or squeezed through the die—that is to say, between the die and the mandrel which has been previously inserted. All tubes except those of half-inch inside diameter and less, and those tubes in which the wall is very heavy relatively to the diameter, are drawn over mandrels in this way. The dies, which, of course, are subjected to very heavy service, are made of the best grade of crucible steel and are machined down to the thousandth of an inch, so as accurately to govern the outside diameter of the tube. The tubes are drawn from two to twenty times through dies of varying diameter and are thus brought down gradually to the required dimensions.

Annealing and Testing

After this cold-drawing the tubes are annealed to take out the working stresses. Cold-drawing makes the tube hard and brittle and, hence, after each draw-pass the tube has to be annealed in order to make it soft enough to withstand the next drawing. Annealing forms scale on the tube, and this is removed by pickling. That annealing is a very important step may be judged

from the fact that it varies from a "light" annealing to remove initial stresses to a "long" annealing in a closed box to render the tubes soft and ductile. Cold-drawn tubes are then passed through the straightening machine and from them to the cutting-off machine, where they are cut to the desired length. The "Shelby" seamless steel boiler tube is subjected to a hydrostatic pressure which varies from 1,000 pounds per square inch in tubes under 5 inches in diameter, to 800 pounds per square inch in tubes over 5 inches.

The Cupping Process

Finally, there is a method of making seamless steel tubing from flat plates by what is known as the cupping process. When a seamless tube of, say 20 inches is required, the rolling and piercing machinery would have to be so gigantic and unwieldy as to become impossible; hence the cupping process is employed. The steel plates for cupping are delivered in squares varying from ⅜ to 4 inches in thickness and from 2 to 7 feet in outside diameter. After heating, the corners are sheared off and the plates are passed to a hydraulic press where they are punched into rough shallow cups. The cups are reheated and again punched through a smaller die to lengthen and deepen them. After a cup of suitable dimensions has been formed it is reheated and drawn through a series of dies in a horizontal bench. A cup may be heated and drawn as many as twelve times before it is a finished tube.

Seamless steel cylinders are made by swaging down the heated end of a tube in a lathe running at high speed. A steel tool is brought to bear against the heated end and closes it up into a semi-spherical form.

CHAPTER XIII

Manufacture of Plates, Sheets, and Tin Plate

In dealing with the work of the rolling mills a selection has been made of the finished products which bulk most largely in the annual output of the United States Steel industry. The chapters immediately preceding deal with steel rails, wire rods and wire, shapes for buildings and bridges, and steel pipe, both welded and seamless. The present and closing chapter of this section deals with the manufacture of plates and sheets, of which 8,087,883 tons was produced in 1924.

"Plates," in the steel industry, is the name applied to the heavier sheets of steel which are used for the armor of warships, for the hulls of ships, and for boilers, tanks, railroad cars, and other constructions that call for rigid strength. Plates are known as sheared or universal, according to the methods by which they are formed in the process of rolling. Sheared plates have their upper and lower surfaces rolled and have their rough edges and ends subsequently sheared. Universal plates are those which have both their surfaces and their edges rolled to size, and only their ends are sheared.

Sheared plates are rolled in a three-high mill, in which the top and bottom rolls are power-driven and are of great diameter. The center roll, which is about

two-thirds of the diameter of the other two rolls, is driven by friction. The top roll is raised or lowered in the housing or standards; the middle roll can be brought in contact, as desired, with the top or bottom roll, which then serves to assist in taking the heavy bending strain on the middle roll. The adjustment of the top roll, to secure the proper spacing for each successive

A 32-INCH MILL AT HOMESTEAD STEEL WORKS ROLLING INGOT INTO SLAB

pass, is done by screws operated by a motor. In the 140-inch mill at Homestead the top and bottom rolls are 38¾ inches in diameter, when new. The middle roll is 22 inches. The rolls are chilled to a depth of 1¼ inches. To operate such a mill calls for great power; it is driven by a 42-inch by 66-inch by 60-inch, tandem, compound engine of 3,500 horsepower at 642 revolutions per minute. The later mills, at Homestead

and elsewhere, are electrically driven by motors of 4,000 to 6,000 horsepower.

The slabs, (thick heavy plates that have been rolled down from the ingot) after preheating, pass through the roughing mill, which is of the reversing type. After the first pass (between the lower and middle roll) the slab is received on the rollers of a tilting table. The table rollers are then reversed and the table is tilted, lifting the slab to the opening between the middle and upper roll, through which it returns in the second pass. These operations are repeated until the roughing operation is completed. To prevent unequal expansion of the rolls, which tend to become heated and therefore of larger diameter at the center than at the ends, streams of cooling water play upon them continuously.

The plate, which has now approached its final dimensions, is brought to its exact gauge, or thickness, in the finishing mill, which is generally similar to the roughing mill. The plate is then moved forward on power-driven rollers to the straightening rolls from which it is conveyed to the "turnover" for inspection. Another conveyor carries it to a table, where it is marked for shearing, which is done by a double rotary shear, which trims it to exact width. The ends are then sheared, and after the plates have been weighed and marked, they are shipped to the customer or placed in stock.

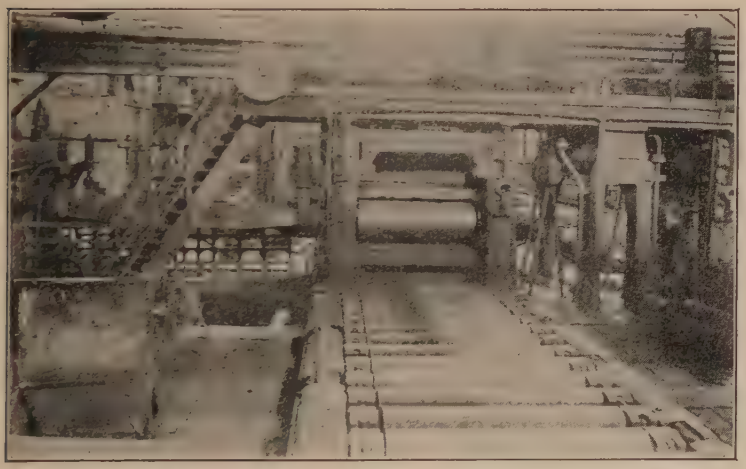
It should be explained, here, that although some of the heavier products are rolled down to finished size direct from the ingot, whose great initial heat is suf-

ficient to maintain a sufficiently high temperature for rolling throughout the whole process, some of the lighter finished materials are so light that the highest initial temperatures attainable without injury to the steel, are not sufficient to complete the rolling. Hence it is necessary to reheat the metal before it is put through the finishing passes. The reheating furnace is operated on the same general reverbatory principles as the blast furnace and the open-hearth furnace, described in previous chapters, the waste gases giving up their heat to brick checker work, from which it is recovered, upon reversal, by the incoming air.

The universal mill, as shown in the accompanying view of a 32-inch mill at Homestead, consists of two horizontal rolls, in front of which are four vertical rolls, a pair on each side of the horizontal rolls, all six rolls being held in a common housing and so geared as to be driven by a single engine. The reduction of the thickness of the plate takes place between the horizontal rolls, as in the sheared plate mill, and the vertical rolls serve to reduce the width of the plate and finish it with the true, parallel edges which, in the sheared plate, are secured by passing it through parallel rotary shears. The plate is now carried on live roller tables to two cooling beds, which extend in opposite directions from the sides of the cooling tables, where any buckling is removed and the edges are flattened out. The plates are then sheared to length.

Universal mill rolling has certain advantages. It is

possible to roll plates of great length with rolled and parallel edges, such as are required in girder construction. Shearing costs are reduced, and the customer is put to less cost for machinery.



HEAVY PLATE MILL, ILLINOIS STEEL COMPANY, SHOWING 132-INCH ROLLS

Sheets

Of sheets—black, blue-annealed and galvanized—it may be said that they enter more intimately, or at least more consciously, into the every-day and domestic life of the people than any of the multitudinous steel products.

Black sheets are used in making modern door frames and window sashes, modern office furniture, including desks and filing cabinets; they are used in street-car bodies, and in ever-increasing amounts for automobile bodies.

Blue-annealed sheets are made into small boilers, tanks, and numerous other familiar objects; while galvanized sheets make their appearance as the covering of roofs and walls of buildings, and as gutters, troughs, rain-water pipes, to say nothing of numerous kitchen fixtures and utensils.

Black sheets are made from sheet bars which have been rolled from the ingot in the blooming and billet mills. These sheet bars are usually 7 or 8 inches wide and 30 feet long. The bars are cut into short lengths of specified weights according to the sheets to be rolled. These are then heated to a cherry red and are rolled down first in the roughing and then in the finishing rolls. The rolls run in brass bearings and the top roll is fed down by screws, as the successive passes are made. As the bar passes through the rolls it is caught in a pair of tongs on the further side, by an operator, the "catcher," and passed back over the top roll to the "rougher," who passes it again between the rolls, the screws having been turned to reduce the opening. If a light gauge of plate is to be rolled, a certain number of the partially rolled sheets are piled into a "pack," which is bent over and doubled longitudinally. The pack is now reheated in the sheet furnace, after which it is passed through the finishing rolls and reduced to the desired gauge. In rolling heavier sheets the doubling is omitted.

The sheets are now sheared to trim and square the edges, pulled apart, piled on buggies, and transferred

to the cold-rolling and annealing rooms. The cold-rolling imparts the desired finished thickness and smooth, fine finish to the plates; but it also renders them hard and brittle. To remove these qualities and eliminate the resulting internal stresses, the plates are annealed. They are piled on a cast-iron base and a cast-iron cover is placed over them, and to exclude the flame, which would cause scale, sand is piled around the lower edges of the cover. The annealing boxes are then pushed into the furnace, where they remain for from two to four days exposed to a temperature of 1,500 degrees Fahrenheit. After removal from the furnace the box, still sealed by sand, is allowed to cool for twenty-four hours. The sheets are then sheared to final size, and given a few final passes through the cold rolls, to secure exact size and a fine finish.

The bluish appearance of blue-annealed sheets is secured by annealing them for a few minutes in direct contact with the furnace flames. After annealing they are straightened out in rolls and sheared to size.

Galvanized sheets are used, as we have noted, for the roofing and siding of buildings, and for utensils and various other purposes where they are exposed to corrosion. The rolled sheets are pickled in sulphuric acid, to remove scale, grease, etc., and are then washed in water and passed through a bath of molten zinc, tin, and lead. Before entering the hot metal, the sheets are again cleaned by immersion in a weak solution of hydrochloric acid. After passing through a flux box

containing sal-ammoniac and tallow, the sheets, one by one, pass through another pair of rolls, are fed into the bath of hot spelter, and are drawn through it by a pair of rolls in the spelter. On emerging from the bath, they pass through a final pair of rolls, which remove the excess spelter and deliver them to a conveyor, by which they are taken to the cooling wheels, in which

DISCHARGE END OF GALVANIZING BATH, SHOWING STRAIGHTENING ROLLS AND DRYING RACKS

each sheet is held separate from its neighbor while a current of air plays upon it. The sheets are then shipped in bundles, or they pass to the roofing department, where they are corrugated between rolls or stamped to shape as desired.

Tin Plate

Since tin plate is black plate covered with a coating of tin, it is not necessary to describe here, in great

detail, the rolling of the black plate, as carried on in a well-equipped tin-plate works. The process of rolling is, in its main features, similar to that employed in rolling the black plates of commerce as above described. The black plate for tinning is rolled from tin bars, which are cut to short lengths and are 8 inches wide and from 3/16 of an inch to ¾ of an inch thick. They are heated to a red heat, and passed in pairs to the rougher, who passes them through the rolls with the grain parallel to the axis of the rolls. After several passes, they are reheated and again rolled, separated, looped over, and flattened. Twice during the successive reheating and rolling the "pack" is doubled over upon itself, so that, after the final rolling, it contains eight separate sheets, the folded edge of the pack having been sheared off to effect the separation.

The packs (of eight plates) are then trimmed by shearing the edges, and are finally cut through the center, so that now there are sixteen squared plates with all edges accurately trimmed. The "strippers" now separate the plates, by peeling them off one by one from the pack.

The plates are next pickled, to remove scale and iron oxide, and inspected. Then follows the annealing, as above described in dealing with black plate, at a temperature of about 1,500 degrees.

They are then put through the cold rolls to give the proper surface finish. The cold rolls are known as the rougher, the intermediate, and the finisher rolls. Next,

to remove the hardness due to cold rolling, the plates are given a mild annealing lasting for eight hours. To remove the light scale, due to this annealing, the plates are pickled in a mild sulphuric-acid bath. They are then placed in water-filled boxes, and wheeled to the tin house.

FINISHING PASS OF TIN-PLATE PACK

The tinning machine is a rectangular cast-iron pot, in the bottom of which is about twelve inches of molten tin. It is heated by gas. The pot is five feet wide by nine feet long. On the side on which the black plates are fed in, and above the tin, is a bath of zinc chloride, which cleans the plate and prepares it to amalgamate

with the tin. On the opposite side, where the tinned plate emerges, is a bath of palm oil floating upon the molten tin.

The black plates are taken, by hand, one by one, from the water boxes, and passed through the zinc chloride into the bath of tin. Here the plate is gripped by a pair of rolls, which force it through the tin into a second pair of rolls, located in the palm oil, which give it luster, and, as it emerges, it passes through a third pair of rolls. The last two pairs of rolls spread the tin evenly over the surface of the plate.

A conveyor now receives the tinned plates and carries them to the disk-cleaning rolls, which are covered with canton-flannel disks. They then pass through the buffing rolls, which give the final, characteristic polish to the plate. The plates are then assorted, inspected, and packed in light wooden boxes for shipment.

CHAPTER XIV

Story of Steel—The Campaign for Safety

Thus far the description of the manufacture of steel has dealt exclusively with the mechanical aspects of this many-sided subject. It is time surely that something be said about the human side—about the men who so deftly and with such easy familiarity control the vast and awesome machinery, and move day by day and night by night among the volcanic fires and ponderous appliances of the furnaces, foundries and rolling mills which have been depicted in the previous chapters.

If space permitted one would gladly dwell in much detail upon the human side of all this and tell how the toiling myriads employ their leisure hours—that is to say, how they live and play; but that must be left for a succeeding chapter. Just now we are concerned with the ever-present and all-important matter of the safety of the employee while he is at work—the protection of the workman against injury and sudden death.

Steel Corporation Protects Its Men

The world at large knows all too little about the very fine work which has been done by the great in-

dustrial interests, and notably by the United States Steel Corporation, to protect their workmen against accidents. On the contrary, the public has been made the victim of a false and very vicious propaganda, which seeks to convey the impression that the policy

SHOWING A LINE OF NAIL-MAKING MACHINES UNGUARDED

of these great corporations aims at getting out of the employee the greatest amount of work with the minimum of expenditure to themselves. In other words, there is an endeavor to show that the workmen are being treated as so much property, to be exploited without any regard for their human and spiritual interests.

Now one of the greatest and most pleasant surprises of the writer's recent extended tour through the great steel works of the country was to find on what a carefully-thought-out and extensive scale the problem of safeguarding the workmen is being solved. Many years ago the United States Steel Corporation organized a Bureau of Safety, Sanitation, and Welfare, whose activities, under a general manager and a very large staff, cover the whole field of the Corporation's steel activities. This good work started in the year 1908, at which time the casualty managers of the different subsidiary companies were called together and Judge Gary addressed them as follows:

Judge Gary on Safety

"Some of the gentlemen present, if not all of them, know that I am in hearty sympathy with the movement. We should like to take a prominent part, a leading part, in any movement and in every movement that is practical to protect employees of the different corporations in which we are interested; any requisition which is made for the expenditure of money to install equipment to protect our people will be honored, and I do not hesitate to say that we expect our legal department, and the gentlemen who are subject to their control (these casualty managers were under their control at that time) and direction and advice, to take such steps as are practicable to ascertain anything that can possibly be done at every locality and

in every department to add to the safety of our equipment and to prevent accidents."

At a later date Judge Gary wrote to the presidents of the subsidiary companies: "The United States Steel Corporation expects its subsidiary companies to make

THIS SHOWS THE SAME NAIL-MAKING MACHINES FULLY GUARDED

every effort practicable to prevent injury to employees. Much can be done by designing new construction and machinery with all practicable safeguards. Expenditures necessary for such improvements will be authorized. Nothing which will add to the protection of the workmen should be neglected. The safety and welfare of the workmen is the greatest concern."

In the intervening years there has been built up a vast welfare organization, the result of whose work is shown in a report entitled "Accidents 1906-1920, inclusive," from which we learn that, during that period, in spite of the rapid growth of the various industries and, therefore, of the total number of employees, there has been a reduction in the number of accidents of 54.05 per cent, and that up to 1920 no less than 29,550 employees had been saved from serious injury.

Developing Safety-first Instinct

The effort of the Corporation to safeguard its employees against accident may be classified under two heads—first, the provision of mechanical safeguards around the moving machinery; and second the training of the employees in habits of carefulness and the avoidance of unnecessary risk. A study of 220,707 accidents reveals some unexpected and very illuminating facts. In the first place, it is found that only 4.94 per cent of the total number, excepting those in connection with overhead electric cranes, was due to machinery causes. While this low percentage results from the protection of the mechanical safeguards installed, Mr. Charles Close, the manager of the Bureau of Safety, assures us that the accidents represented even by this low percentage do not indicate that the machines were not properly guarded, since employees do get hurt through their own carelessness, even though

the machines are completely equipped with safety devices.

Hand labor, we are told, caused 44.42 per cent of these accidents, the majority of which cannot be controlled by any safety devices and appliances. The conditions under which these accidents occur are almost

AN ENGINE AND GEARS, FOR DRIVING WHEEL ROLLS, WITHOUT PROTECTING SHIELDS

wholly within the control of the workmen, and are due largely to their thoughtlessness or carelessness. In addition to these hand-labor accidents there are hundreds of others, where the carelessness or thoughtlessness of the employees were contributing causes. As a matter of fact, a careful analysis of any 100 accidents

shows that at least 90 of them might have been prevented if a little more care had been exercised.

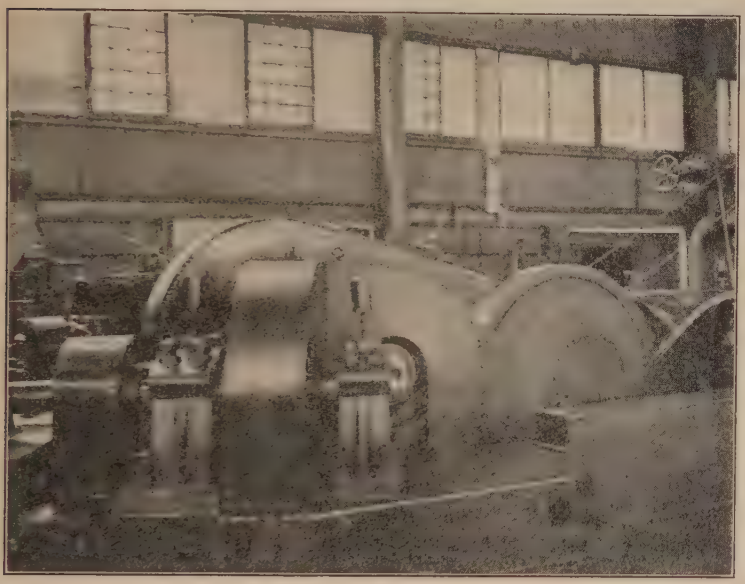
A Few of the Safety Devices

The accompanying photographs will suffice to show the general character of the safety appliances. The danger from swiftly running belts and pulleys is to be found in all shops except those, indeed, which have equipped their tools with the electric motor—a great safety device in itself. A large percentage of the accidents are due to workmen being caught between a pulley and its belt, or having their fingers or hands crushed between reciprocating parts of a machine. The surest safety guard (next to inculcating habits of caution in the employee) is to cover up these moving parts by some form of metal construction in the form of bars, or sheet and wire-net guards.

The two views of a large shop in the nail department of a modern mill show how effectively the belts, pulleys, and reciprocating parts of the nail-making machines may be shielded by placing around each machine a stout sheet-iron casing, which, while it in no way interferes with the operator, prevents him from making accidental contact with the moving parts.

Not only small machines, such as the above, are shielded, but it is possible, in most cases, so to cover up the heavier machinery, that nothing but gross carelessness on the part of the employee could result in

his injury. The risk of grave injury, if not of death, is very real in the steel rolling mills, where swiftly rotating, heavy gear wheels, surrounded by greasy platforms, are an ever-present menace. An excellent ex-



THE SAME ENGINE AND GEARS, SHIELDED TO PROTECT THE WORKERS

ample of protective appliances is shown in the two companion views of an engine driving a set of steel wheel rolls through heavy spur and miter gears—one view showing the machinery unprotected, the other affording striking evidence of what may be done for the safety of the employee.

Most Accidents Due to Carelessness

The experience of the Safety Bureau indicates that more accidents happen where the conditions are entirely within the control of the workmen themselves, and are, therefore, due to carelessness or thoughtlessness, than those which are directly due to machinery causes.

Now this analysis shows the enormous importance of the safety-first campaign which is being carried on ceaselessly by the Safety Bureau, in the effort to induce in the workmen what might be called a safety-first instinct. Mr. Close believes that there will come, ultimately, a day of no accidents, but he believes that to bring that about it will be necessary to develop a new generation of workmen. This can be done by training the child so that he will develop habits of safety. It is not enough to show him the safe way of doing things once, twice or a dozen times. To get results it is necessary to teach him the safe way of doing things every day "so that when he comes into the shop as a workman he will habitually do the safe thing, just as his father today seems habitually to do the unsafe thing."

Hold the Foreman Responsible

It is believed that under the existing conditions, and with the present generation of workmen, safety can be promoted by holding the foreman responsible

for the accidents in his department, and by charging the accident costs against the cost of his product. The foreman is in his position to keep up production and to keep down costs. The cost of accidents ultimately is included in the cost of the manufactured product, and it is suggested that this should be included in the manufacturing cost of each department, thereby impressing it upon the foreman whose men are having accidents that the work of his department is more expensive than that of the foreman whose men do not have accidents.

Of course the trouble is to be explained as verifying the truth of the old saying that "familiarity breeds contempt," and it is this day-by-day familiarity with danger that leads the workmen to look upon disablement and death, not so much as an ever-present threat, but as companions which are so familiar that they have lost their sinister aspect.

CHAPTER XV

The Story of Steel—Welfare Work

In preceding chapters we have described the triumphs of applied science, invention and industrial organization, which have raised the steel industry of the United States to its present commanding position. The present

EMPLOYEES' HOSPITAL, FAIRFIELD, ALABAMA, ACCOMMODATING 348 PATIENTS, AND EQUIPPED WITH THE MOST MODERN APPLIANCES

chapter is devoted to a brief sketch of what in our opinion is the greatest triumph of all—namely, the bringing of capital and labor together in a bond of mutual human interest and understanding, without which the present prosperity of the industry would be impossible and its future would be sorely jeopardized.

The industrial pioneers of America were so occupied in the struggle to overcome obstacles and in the development of processes, that they lost sight of, or could give only slight consideration to, the human side of steel-making. They were men of courage who started the industry, and it took men of determination and perseverance to develop it to its present magnitude. In a period of about fifty years, thanks to their efforts, an industry has been built up which employs over 600,000 people and produces annually over $1,600,000,000 worth of a material which is absolutely essential to our modern civilization.

Demand for Safety and Comfort

The aim of the early plant officials was directed to production almost exclusively; but times have changed and, although production is still the ruling factor, there has developed a growing recognition of the claims of the workingman, that his work shall be rendered safe and that his living conditions shall be improved to keep pace with the developments of our social life in housing, health and recreation.

"Today," says one of the leaders in this good work, "welfare work may be classified as one of the essential features in successful and efficient plant management." It will scarcely be disputed that in the work of bettering the conditions of labor in the steel industry, the leading spirit has been Judge Gary, the present venerable president of the United States Steel Corpora-

tion. It is significant that during an interview before the writer undertook his lengthy trip through the steel industries, the whole hour was consumed by Judge Gary in outlining what had been done for the workingman. Asked what he considered to be the most important requisite for a successful head of a steel plant, he replied, "I would place first a thorough knowledge of human nature, as exemplified in the American workingman, and an intelligent sympathy with his point of view."

A Great Welfare Organization

In the present chapter we shall deal, only too briefly, with what has been done in the way of general welfare work. It was shortly after 1906 that the Steel Corporation appointed a safety committee comprising officials of the Corporation and representatives of the larger subsidiary companies. The work grew to such an extent that there was organized, in March, 1911, a central station which was known as "The Bureau of Safety, Sanitation and Welfare."

In addition to the work of accident prevention already dealt with, the work of this bureau is grouped under some score of welfare activities. Obviously, we can touch only lightly upon a few of these institutions, and we must leave the telling of the story to the accompanying photographs.

First-aid and rescue crews have been formed, whose object is to have especially trained men to take imme-

diate charge where a life is imperiled. After first aid the victim is carried at once to a completely equipped emergency hospital, and we show one of these recently built at Fairfield, Alabama, by the Tennessee Coal, Iron and Railroad Company, at a cost of over one million dollars. The corporation early realized that the burden of caring for the injured should be borne by the

EMPLOYEES' HOMES OF CONCRETE BLOCK CONSTRUCTION, IN MONGAN PARK, MINNESOTA

industry, and they established a voluntary accident relief plan, thereby anticipating the workman's compensation law which was subsequently enacted by the various states.

The Committee on Sanitation has prepared specifications which include regulations for toilets, wash and locker rooms, and drinking water. To avoid infection no wash basins are installed—the men wash in

the flowing stream. Sanitary fountains are used exclusively and sources of drinking water are periodically inspected and the water analyzed. The drainage of marshes and lowlands and the use of crude petroleum have reduced the cases of malaria fever in certain districts from six thousand to two hundred annually.

FRENCH FOLK DANCES, PERFORMED BY EMPLOYEES OF THE TENNESSEE COAL, IRON AND RAILROAD COMPANY. A FEATURE OF WELFARE WORK

The provision of plant restaurants eases the home burden of the housewife by relieving her of the daily preparation of the dinner bucket, and a half an hour earlier to the mill enables the employee to take his breakfast at the restaurant rather than at home, if he so wishes.

A notable work is the institution of clubs, and some

extremely fine buildings have been erected in this connection. The Good-Fellowship Club was organized for the mutual help of all of its members. It assists in the payment of insurance policies, and the visiting nurse on relief work gives assistance and instruction for the comfort and welfare of the families of the members. The visiting nurses, whose services are offered free by the company, visit the homes of the employees on request. They attend the sick, give instruction in domestic hygiene, advise the families in their various troubles and conduct day nurseries for the children.

The practical housekeeping centers teach the preparation and cooking of food, the care and feeding of babies, dressmaking and domestic science.

Housing and Model Villages

In connection with some of the steel works, whole villages have been built from the ground up, where homes fitted with all the modern conveniences are provided at moderate rentals. Gardening is encouraged by the offering of prizes for the best gardens, and the company usually plows the community gardens at its own expense, plots it out and directs the workmen in their gardening activities. Flower gardening at the works is encouraged and is done mainly by the employees. Limitation of space prevents any detailed notice of the various picnics at which the musical bands of the workmen play, or of the large extent to which athletics are encouraged.

We cannot close without mention of the educational work carried on and of the endeavor to thoroughly Americanize the newcomers from Europe, and also of the

AN EMPLOYEE'S GARDEN. THE UNITED STATES STEEL CORPORATION ENCOURAGES GARDENING BY OFFERING PRIZES FOR THE BEST DISPLAY

stock subscription plan which has been so successful that by April 20, 1920, over forty thousand employees were stockholders, and their holdings represented a total of $18,600,000.

CHAPTER XVI

Distributing the Finished Product

How is the country's steel production disposed of? By what means is this stream of finished steel products guided to its final destination? The steel production of the entire world is at the rate of about 75,000,000 tons per annum, of which approximately one half is produced in the United States, and of this half, about 50 per cent is produced by one organization, the United States Steel Corporation, whose rate of production therefore accounts for approximately 25 per cent of the production of the entire world.

It will be interesting to examine the means by which this tonnage is distributed and the extensive sales organization which must function efficiently to secure orders covering this tonnage, orders in the case of the United States Steel Corporation amounting to some 40,000 to 50,000 tons each business day. The bulk of this tonnage is covered by orders for comparatively small lots; it is not the larger orders of 5,000, 10,000, 20,000 tons and more which make up the bulk of the tonnage.

First let us see where the material goes, into what uses and to what markets. About 10 per cent to 15 per cent is exported. Of the remaining 85 per cent to 90 per cent, from 25 per cent to 30 per cent goes to the rail-

roads of the United States for their many steel requirements—tracks, cars, locomotives, bridges, etc. About 12 per cent enters into the construction of our motor cars and 15 per cent into the construction of bridges and buildings. The balance goes largely to manufacturers of thousands of articles in common use. These smaller items, perhaps, constitute the more important and profitable portion of the tonnage of a steel mill. Looking over the catalogue of products, we find such items as bale ties, clothes lines, music wires, band-saw steel, toe calks, corset steel, bed springs, window-sash sections, bedstead tubing, fence posts, car wheels, steel sheet piling, wire ropes, rubber-tire channels, concrete reinforcement, metal lath, etc.

The export tonnage of the Corporation is handled through one subsidiary selling organization with its main office in New York City and branch offices strategically located at the main centers of the world's steel importing markets. These sales, running at times up to 20 per cent of the total mill production, are an important factor in keeping the mills and furnaces engaged at an efficient rate of production and at the same time giving added employment to American workmen. Projects of considerable size and importance often arise in the export field, as for instance recently, the bridge over the harbor at Sydney, Australia, where 50,000 tons were involved in one contract which was finally awarded to an English firm after a close contest with several firms of bridge-builders of this coun-

try. Last year, a contract for 40,000 tons of galvanized sheets was taken by an American mill for shipment to the Argentine for use in building a steel wall to prevent the migration of swarms of locusts. Salesmen in such projects are engaged in an interesting and keen competition with the manufacturers of England, France, Belgium, and Germany. Foreign exchange, ocean freight rates, marine and sometimes war-risk insurance, financing and other items, enter into and complicate these transactions.

The greater portion of the steel manufactured here is of course sold for use in our own country. Because of the many variations with respect to size, shape, and quality, practically all of this tonnage is produced to order, hardly any of it is manufactured and stocked to await incoming orders. It therefore behooves the sales forces to keep the mills supplied with sufficient orders to permit of continuous production and at a rate sufficiently high to give low-cost production, having due regard to prices ruling and tonnages available. The steel industry seems particularly susceptible to extremes of prosperity and depression. Why this should be so is a question often discussed and the reason is probably to be found in the fact that in times of low demand the temptation is strong to take orders at concessions in price and even at a loss in order to enable the mills to maintain operations at a rate which will permit of low-cost production. In other words, the spread between the cost of producing steel when operating at 60 per cent

capacity and the cost when operating at 80 per cent capacity is greater proportionately than in almost any other line of industry.

Generally speaking, each producing company has its general sales offices located at a point near its mills, with branch offices in all large consuming centers. An average list of branch sales offices would include Boston, New York, Philadelphia, Baltimore, Buffalo, New Orleans, St. Louis, Chicago, Cleveland, Cincinnati, St. Paul, Los Angeles, San Francisco, and Seattle. These branch offices are all subject to and under the direction of the general sales office. In some cases separate sales offices are maintained in each city for products of a different class, such as wire, tubes, sheets, etc. In other cases all offices are combined in each city under one general office. A few of the larger companies also carry stocks of some of their more common products in warehouses located in the larger consuming centers.

The responsibility of the head of the sales forces is great. He must maintain a balance between tonnage and prices, he must supply the needs of the mills for tonnage and at the same time secure prices which shall, in the long run, show reasonable profits to the stockholders. The supply is a known factor, the demand is problematical, and he must keep in close touch with his markets, else he will be unable properly to gauge the trend of the market and the wisdom of pressing material for sale or holding reserve mill capacity for

more remunerative prices. With the greatly enlarged capacity of the steel mills of this country and the multiplying uses to which steel is put, the commercial side of a steel organization has assumed a position of equal importance with that of the producing side.

CHAPTER XVII

The U. S. Steel Corporation's Financial Policy

When Bessemer, by the invention of his converter, made possible the production of cheap steel rapidly and on an enormous scale, he started a rush into the business of steel-making which was as wild and fierce, in its way, as the rush of the prospector and the miner into a newly discovered gold field. The industry progressed by leaps and bounds, new works sprang up overnight, and the one idea that possessed the ironmaster was production, the turning out of a maximum amount of "tonnage." Fierce competition was rampant; and so far as the interrelationship of the various ironmasters was concerned, it seems to us, as we look back upon it, to have been based, first and last, on the principle of "cut-throat" competition. It was a case of "dog eat dog." At the same time the more thoughtful and far-seeing seem to have realized the need for some sort of understanding or cooperation in distributing and selling the ever-growing output of their furnaces and rolling mills; and, from time to time, contracts and agreements were drawn up. But however well-intended these arrangements may have been, however sound in theory, they failed disastrously in practice. These commercial treaties too often proved

to be mere scraps of paper, and the steel industry remained in a state of continual upheaval. As Carnegie once remarked, the ironmaster was "prince today, and pauper tomorrow."

Out of this welter of competition there began to emerge, in the person of Andrew Carnegie, a man who, by virtue of his organizing ability and his genius for selecting and surrounding himself with men of high ability, built up a vast aggregation of furnaces and rolling mills, coke ovens and so forth, until he towered like a giant among his competitors. No one realized more clearly than he the serious disadvantages under which the steel trade in the United States labored. The industry was in the hands of disunited and fiercely competitive men, whose total lack of coordinated effort was the fundamental cause of the disastrous fluctuations to which the trade was subjected. The remedy, as he saw it, was to consolidate several of the more important concerns into one great corporation. This he achieved, and because of the economies thereby realized and the cheapening of the product which resulted, to say nothing of his general business ability, he became the most powerful agent in carrying the steel trade of the United States up to the commanding position which it had attained at the close of his active career. But Carnegie himself seems to have believed in the methods of ruthless competition which prevailed in his day; and though his genius had sufficed to place him and his steel properties in an unrivaled position, he did but little,

if anything at all, in the direction of getting his competitors together in some sort of agreement as to prices, and substituting cooperation for the merciless competition of the day.

By a most fortunate coincidence, it so happened that at about the time when Carnegie was ready to sell out his interests and retire to private life, there was another man in the person of Judge Elbert H. Gary, who was actively endeavoring to amalgamate several great steel properties in one large corporation. His aim, like that of Carnegie, was to secure the great economies which would result from such an amalgamation; but his outlook was far broader than that of the great ironmaster. Judge Gary believed that the competitive methods of the day were a most serious obstacle to the full development of the steel industry of the United States as a whole; and it was his idea that it would be possible for the great combination which he had in mind to use its influence to establish business relationships of a high ethical and moral kind throughout the whole steel trade, to introduce wide-open publicity in place of secrecy, to emphasize the principles of fair play and the square deal, and thereby sweep away at once the bitter hostilities, the business uncertainties, and the distressing fluctuations that had marked the first half-century of the steel industry in America.

Judge Gary, born on a farm near Wheaton, Illinois, and educated as a lawyer, was at this time president of the Federal Steel Company, organized in 1898 as a

merger of the great Illinois Steel Company and other large concerns, which he was anxious to enlarge to a point where it would command its own mines, coke ovens, and transportation facilities, and not only be strong enough to bring about a reform of the business methods in America, but to enter into successful competition with Great Britain and Germany.

The acquisition of the vast Carnegie plants, which had realized profits in 1900 of about $40,000,000, would give the proposed combine the position at which Gary was aiming. It was known that Carnegie wished to sell. It remained only to get the leaders together and secure the services of a master of finance who was capable of engineering this great transaction. Such a man was found in J. P. Morgan. At a memorable private dinner on December 12, 1900, to which Mr. Morgan was invited, the matter was discussed, and as the result, largely, of the enthusiastic unfolding by Charles M. Schwab of the benefits to be derived from the amalgamation, Morgan was won over to the project. From that day, matters moved so rapidly that the United States Steel Corporation was chartered on February 25, 1901, and began business as a corporation on April 1, 1901.

The Carnegie properties were acquired at Carnegie's price of $303,450,000 in bonds and $188,556,160 in stock of the new corporation. Vast as were the properties included in this amalgamation, it did not even yet cover the field sufficiently. There were many steel

products that bulked hugely in the country's steel output, that were not made by either the Federal or Carnegie companies. Among these were tubes, wire, tin plate, etc. It was desirable, moreover, to secure iron mines and ships for the transportation of the ore. So, in order to place the Corporation in a position to turn out every kind of steel product from a wire nail to a skyscraper, no less than eight additional companies were included. The aggregate capital of the ten concerns was $867,550,394. They were as follows:

Company	*Common Stock*	*Preferred Stock*
American Bridge Company.....	$ 30,527,800	$ 30,527,800
American Sheet Steel Company.	24,500,000	24,500,000
American Steel Hoop Company.	19,000,000	14,000,000
American Steel & Wire Company	50,000,000	40,000,000
American Tin Plate Company..	28,000,000	18,325,000
Carnegie Steel Company.....	160,000,000	160,000,000 [1]
Federal Steel Company.....	46,484,300	53,260,900
Lake Superior Consolidated Iron Mines.....	29,424,594	.....
National Steel Company.....	32,000,000	27,000,000
National Tube Company.....	40,000,000	40,000,000
Total.....	$459,936,694	$407,613,700

[1] These are bonds. Other figures in column are preferred stock.

The United States Steel Corporation was given an authorized capitalization of $550,000,000 in common stock, $550,000,000 in preferred stock, and $304,000,000 in bonds, or the vast total of $1,404,000,000. This was to provide for the exchange of new stocks

and bonds for the securities of the companies that entered the combine. To provide sufficient working capital at the commencement of operations under the new corporation, $25,000,000 was subscribed by the syndicate and the Morgan firm.

This was a huge aggregation of capital; but consider some of its assets: 149 steel works, with an annual capacity of 9,400,000 tons of crude and 7,700,000 tons of finished steel; 78 blast furnaces capable of producing 7,400,000 tons of pig iron; over 500,000 acres of coking coal lands; over 1,000 miles of railroad; large areas of rich ore-bearing lands with unknown millions of tons of developed and undeveloped ore; a fleet of 112 vessels on the Great Lakes for transporting the ore, together with the necessary docks and loading and unloading facilities, to say nothing of valuable natural gas, limestone, and other properties.

Thus was Judge Gary's dream brought to fruition. But would it work? Was this gigantic combine operable? Would it not crumble under its own weight? What about that half a billion dollars of common stock, with no tangible assets back of it—"pure water," apparently. And, as for the "square deal" in the competitions of the steel industry, here was a giant with strength sufficient to snuff out any outside competitor who should dare a passage at arms!

Well, the answer to these forebodings is writ large and clear in the subsequent history of the corporation. The fears have been unwarranted; the promises have

been fulfilled. Whatever "water" may ever have existed has long ago been squeezed out; production has been doubled; wages have increased; dividends have been paid; the vast plant has not only been maintained in first-class condition, but it has been steadily enlarged. And as long ago as October, 1919, Judge Gary asserted before a Senate committee that the properties of the Corporation were actually worth in round figures $2,200,000,000. This was some $700,000,000 more than its funded and stock capital. In the twenty-three years of its existence (1901 to 1923), the total output had risen from 9,000,000 tons of steel ingots in 1901 to 20,329,950 tons in 1923. During the period 1901 to 1924, the profits were $2,106,008,665, and out of this was paid in dividends on the common and preferred stock a total of $1,218,452,933, leaving a surplus of $887,555,732. Of this surplus, over 370 millions was appropriated for payment of capital expenditures and special charges, leaving a balance of undivided surplus, on December 31, 1924, of $517,061,308.

Just here, it will be pertinent to insert a statement of the assets and liabilities of the Corporation:

After deducting from gross sales and earnings of $1,263,711,469 the operating charges, which include the sum of $1,091,746,736 for manufacturing and producing cost and operating expenses, there is left a total net manufacturing, operating, and producing income of $128,097,711. Other income and charges bring the

CONSOLIDATED GENERAL BALANCE SHEET

DECEMBER 31, 1924

ASSETS

Properties, owned and operated	$1,678,208,569
Mining royalties	57,135,602
Deferred charges	3,089,811
Investments	14,791,748
Sinking and reserve fund assets	110,348,190
Current assets (inventories, bills receivable, etc.)	550,620,745
	$2,414,194,665

LIABILITIES

Capital stock of U. S. Steel Corporation	$ 868,583,600
Capital stock of subsidiary companies	514,329
Bonded, mortgage, and debenture debt outstanding	511,272,930
Subsidiary companies' non-interest-bearing notes	28,701,259
Current liabilities	122,959,118
Total capital and current liabilities	$1,532,031,236
Sundry reserves	164,203,207
Appropriated surplus to cover capital expenditures	200,898,914
Undivided surplus of U. S. Steel Corporation and subsidiary companies	517,061,308
	$2,414,194,665

balance of earnings to $153,114,812. Deducting from this, charges and allowances for depletion and depreciation of $48,892,837, leaves a net income for the year of $104,221,975.

PRODUCTION IN 1924 AND 1923

	Tons, 1924	*Tons, 1923*
Ores Mined	24,774,541	31,015,109
Limestone quarried	5,033,889	6,575,694
Coal mined	27,738,007	35,289,901
Coke manufactured	14,408,041	18,837,631
Blast furnace production	12,683,729	16,729,226
Steel ingot production	16,478,857	20,329,950
Steel products for sale	11,722,908	14,721,469
Universal Portland cement	15,156,000	14,440,000

But how has labor fared amid all these gigantic operations, fiscal and manufacturing?

The average number of employees in service of all the companies during the year was 246,753. The average earnings per employee per day was $5.74. If we include the general administrative and selling force, the average earnings are raised to $5.85 per day. The total payroll for 1924, at these rates, was $442,458,577. On December 31, 1924, there were 49,152 employees who were registered stockholders, holding an aggregate of 149,451 shares of preferred and 538,553 shares of common stock. Pensions were paid during the year to 4,478 retired employees, to the amount of $1,683,921. Since the inauguration of the plan in 1911, a total of $11,227,156 has been paid in pensions. The work done in the prevention of accidents has been dealt with in a previous chapter. In 1924, the number of disabling accidents per 100 employees was 75.69 per cent less than in 1912, and in serious and fatal accidents, it was 54.65 per cent less than in 1906, when the safety-first campaign was inaugurated. The payments during the

year for accident relief totaled $5,080,775. The expenditures for sanitary equipment (drinking fountains, comfort stations, showers, lockers, etc.) was $3,231,880.

This chapter would not be complete without some mention of the policies which have guided the United States Steel Corporation so successfully through the first twenty-three years of its operation. They are the policies of its venerable president, to which, at least on their ethical side, some reference has already been made. These policies may be summarized under the heads of honesty, publicity, security, and the square deal to stockholders and employees, and to competitors in the general steel industry.

Let Judge Gary speak for himself. He is addressing the stockholders at the Annual Meeting, April 20, 1925:

> I have always stood for giving all the stockholders the same information at the same time, and giving no one on the inside, or wherever he is, any advance information that will permit him to profit at the expense of other stockholders. . . .
>
> Our statements of earnings come out every quarter. I do not know what the earnings are for this quarter, and I will only throw out the assertion, without being able to prove it on this occasion, that I believe during this quarter we will make a living; but I will not know the figures until about the time the finance committee meets next week Tuesday; then they will be brought to me by the comptroller, who makes them up at that time and brings them in to me when they are ready, and the finance committee meets. The figures are given to the finance committee, and when they adjourn they go into the directors' meeting—not one of them having the opportunity, if he had the disposition, which he has not, to go out anywhere and trade

on the basis of his information; and the figures are given to the board of directors at three o'clock, and then at the same time they are given to the public. The market is closed and no one has an opportunity to get to the stock market for the transaction of business until the next day at ten o'clock.

Now that does not require any superior degree of honesty or fair dealing; it is simply the application of a principle thousands of years old, of doing unto others as you would like to have others do unto you. And that is also the highest degree of intelligent transaction of business. . . .

You may be assured the present management of the Steel Corporation will conduct its affairs in every respect from the standpoint of good business, safe management, good morals, and the general public interest, just as reasonable, sensible stockholders would like to have them.

Later in the year, at the semiannual meeting of the Iron and Steel Institute, speaking on his favorite topic of business integrity, he said:

Why are we not always successful in our business, gentlemen? For a moment let us look into our own hearts and see if we can find any reasons. I offer the suggestion, for your approval or rejection, according to your own best judgment, that lack of success in our lines of business, to a greater or less extent, results from lack of confidence in each other. We do not always believe and depend upon what our business neighbors say. We believe that our neighbors are selfish in the extreme. And that is more or less true. But we overlook the fact that it is just as true of ourselves. There is not a man in this room who would not like to do the right thing, who would not prefer to be absolutely honest and fair and to have his neighbors rely upon him as such.

The members of the Iron and Steel Institute, whose predecessors did not always have the best reputation in business, have reached the moral and the intellectual position of realizing that it is better, from every standpoint, for a man to be square and decent in business. . . .

CHAPTER XVIII

The Marketing of Steel[1]

Steel-making is a basic, underlying industry. The demand for steel is a demand for transportation, for machine-made goods, and for the products and services of machine-made goods. Rolled steel, as previously shown, is produced by large-scale methods according to well-known specifications and, for the most part, on orders placed by industrial users and jobbers. It is wanted for purposes of capital construction and as raw material in the manufacture of innumerable lines of durable goods. This relation of the industry to the fixed-capital requirements of other industries and to the demand for relatively durable goods is an important elementary consideration in any discussion of the problems of marketing.

The logical first step in such a market analysis is to classify the major uses of steel. At the outset it must be recognized that steel consumption varies with the variations in all industry. It is idle to assume that there are fixed, "normal" percentages of consumption by the various classes of steel-users, unless "normal" be defined as a moving average. It is quite as important to determine the trends and variations in the use of

[1] By Edmund Brown, Jr.

steel as it is to set up a list of the leading consumers in order of their relative importance. Over a period of years both the *quantity* and the *proportion* of steel taken by any one industry show marked variations.

At any given time one industry will be demanding more and more steel for capital improvements, while another which is already well developed will require steel only for replacements and repairs or as raw material for manufacturing purposes. Thus the building and construction industry, for the past four years, has been absorbing an increasingly large part of the output of steel. This industry has not only been demanding a much greater quantity of steel, but its demands have increased more rapidly than those of several other industries. It has been a customer second only to the railroads in volume of steel consumed. Yet there are indications today that the building boom in many centers is being carried too far. And if past experience is a safe guide, it may be expected that this movement will overshoot the mark by a considerable margin, resulting in an abrupt diminution of the demand for structural steel.

An analysis of steel consumption, then, must include three considerations: (1) The quantities of various types of steel being taken by the leading consumers; (2) the trend of actual consumption by each important consumer; and (3) the trend of *relative* consumption by each important consumer or group of consumers. In other words, one should know the variations and trends

of steel consumption in general and also the relative importance of each industry as a consumer of steel products.

Such an analysis is presented in the chart on page 170.

This analysis may be summarized as follows:

1. The railroads (including car-builders and locomotive works) came into the market heavily for steel in 1923. Since that year railroad consumption of steel has shown a marked decline in relation to the total output. Railroad buying—especially of cars and locomotives—comes in waves, the heaviest orders often being concentrated in a few months. Over a period of years they may be expected to take a quarter of the steel output.

2. The building and construction industry has taken an increasingly greater percentage of the steel produced during the past few years. It cannot be expected that this rate of expansion will be maintained.

3. Oil, gas, and water companies, while increasing their actual consumption in 1923 and 1924 (over the preceding years) became progressively a less important factor in the market.

4. An outstanding feature is the steady upward trend in actual and relative consumption by the automotive industry. Back in 1921 the automotive industry was taking less than 5 per cent of the total steel products shipped. In 1926 they are using nearly 15 per cent of this volume.

CONSUMPTION OF STEEL PRODUCTS

(Source: Annual number of the *Iron Trade Review*, January, 1926)

	1925		1924		1923		1922	
	Tonnage	Per cent of total	Tonnage	Per cent of total	Tonnage	Per cent of total	Tonnage	Per cent of total
Railroads	5,986,569	22.74	5,924,601	27.54	7,173,868	31.02	4,035,386	24.96
Buildings[1]	4,106,205	15.32	3,106,601	14.44	3,128,992	13.53	1,913,583	11.83
Oil, gas, and water	2,160,667	7.86	1,816,729	8.43	2,451,783	10.60	2,398,910	14.84
Automotive	3,905,683	14 58	2,445,063	11.37	2,449,245	10.59	1,451,632	8.98
Exports	1,204,274	4 49	1,267,201	5.89	1,438,647	6.22	1,226,342	7.83
All others	9,439,218	35.01	6,954,837	32.33	6,485,541	28.04	5,102,696	31.56
Grand total	26,802,616	100.00	21,515,032	100.00	23,128,076	100.00	16,168,549	100.00

[1] Exclusive of railroad bridges and buildings.

1925 based on returns from 83.76% of total capacity.
1924 based on returns from 81.90% of total capacity.
1923 based on returns from 75.84% of total capacity.
1922 based on returns from 70.88% of total capacity.

Importance of the Jobber

It has been variously estimated that from 10 to 15 per cent of the country's rolled-steel product is handled by jobbers. That is, this proportion of the aggregate output is bought by dealers and distributed from their stocks, rather than being sold direct from the mills.

These figures, however, are of little significance in measuring the importance of the jobber to the industry. The jobber does not undertake to carry all products in stock. Standard section rails are customarily sold direct to the railroads and relatively small tonnages of plates and shapes are handled by jobbers. On the other hand, jobbers handle probably 75 per cent of the output of merchant pipe and they distribute bars, wire nails, sheets, and tin plates in large volume.

The jobber's main functions are (1) to carry stocks for quick delivery to near-by consumers and (2) to handle the small-order business in the areas tributary to his warehouses. Steel products sold to a jobber in large lots and shipped on carload rates will be distributed by him in smaller lots over a much shorter radius. Theoretically, at least, in addition to the service of carrying stocks he is in position to reduce the total transportation, selling, and credit expenses on all small orders.

Prompt delivery is a highly important feature of the jobbing service. Most mills cannot roll an individual order for a few pieces or a few hundred pounds until

they have accumulated sufficient tonnage of this form and size of material to warrant it. Otherwise their rolling schedules would be far from economical. The jobber, on the other hand, can make prompt delivery from standard sizes and shapes in stock.

Under conditions of hand-to-mouth buying, traffic congestion, or slow deliveries from the mills, reliance must be placed on the jobber's stocks to meet immediate consumptive requirements.

Take the year 1922, for example, following several months of severe depression. Mill operations were restricted, coal-miners and railroad shopmen were on strike, freight traffic was congested, and embargoes were imposed before the close of the year. During the second quarter, as demand improved, mill prices were advanced and steel-users found themselves short of stocks and unable to obtain shipments. Many large buyers, having orders large enough to interest mill salesmen, were nevertheless forced to resort to warehouse stocks to fill their needs.

The jobber performs more than an emergency service, however, since there are always some consumers who want quick deliveries of steel. A hardware jobber in Des Moines suddenly has call for a car of concrete bars. In ordering from a steel company he would have to wait his turn on shipments. He can wire a jobber in Chicago and rest assured that (under normal traffic conditions) the car will be rolling on its way in from twenty-four to forty-eight hours.

The jobber operates as a distributer to small consumers—contractors, small railroads, and manufacturers, as well as hardware stores. He is usually located in a large center where he can serve local industries and make delivery by rail over a wide territory. Frequently a consumer will need only an odd piece or two to complete a job, and the possibility of getting this from a local jobber saves him loss and inconvenience.

The jobber apparently does more business in lines controlled by a few large producers than in lines put out by numerous smaller concerns. Thus the proportion of steel tubular goods handled by jobbers has steadily increased, while their share in the sheet and tin-plate business has declined from about 25 per cent (around 1900) to about 10 per cent today. This is attributed to the fact that so many small concerns have entered the sheet and tin-plate business. The small mill expects to serve small consumers who would otherwise buy from jobbers. In fact, the acceptance by some mills of orders small enough to be considered "warehouse business" has been a recurrent complaint from the jobbers. In 1925 a committee representing the distributers tried to effect an agreement among the steel companies as to the minimum tonnage which a mill would accept. This was unsuccessful. Some of the larger mills were willing to protect the jobber and declined to fill small orders; but they often found that these orders were filled by other mills. The smaller mills which do little or no business with jobbers feel under

no obligation to turn down small orders which happen to fit in with their operating schedules.

Some of the Eastern mills, especially in slack times, have accepted orders for one or two plates at close to carload prices. As a result, stocks of plates have almost disappeared from some jobbers' warehouses.

Only in the concrete bar trade have definite lines been drawn between the mill and the warehouse business. Here the jobbers are allowed discounts on orders for mill shipments, the sales being made at mill prices. On prompt warehouse shipments they obtain the full warehouse price.

As a general rule, many mills will consider any order amounting to one ton or more of a given item. Yet the volume of business remaining to the jobber is very considerable and shows no signs of diminution.

Advertising

It is often assumed that competition for steel products rests entirely on a price basis—that standardization has been carried to a point making quality, or distinctiveness of product, a negligible consideration. For many of the ordinary sizes and shapes this is, of course, true.

Yet there are many differences in form and quality and numerous specialized products which lend themselves to advertising and demand creation. The production of alloy steels, for example, which is a rapidly growing branch of the business, includes items widely

dissimilar in composition and commercial use. As a result, advertising is employed quite extensively for steel specialities, although it is largely confined to class journals.

Moreover, it has recently been recognized that advertising campaigns for the trade as a whole are of definite importance. This is exemplified in the work of the Sheet Steel Trade Extension Committee. This organization has advertised the uses of sheet steel through numerous mediums, by no means confining its effort to the trade journals. A notable instance of their work was a prize contest for designing artistic garages as a means of overcoming municipal ordinances forbidding the erection of unsightly sheet-steel structures.

Price Stability

Most factors in the steel industry are opposed to anything in the nature of speculative trading or scalping. Rolled steel products have some of the attributes required of a commodity for speculative trading and are quite akin to cotton, wheat, and other staple products in this respect. The standard sizes and shapes are demanded recurrently by users everywhere, regardless of where the steel is made. Steel products are non-perishable and interchangeable. The processes of manufacture are well known and the standard shapes and sizes need not be identified with any particular mill. Variation in quality is relatively unimportant. Speculation in spot steel is quite feasible and, theoretically, it would not be impossible to organize a market for trading

in steel futures. In England there has been active trading in pig iron warrants for many years.

Yet there is little likelihood that such a futures market will ever be organized in the United States.[1] There is, indeed, no need for a futures market under present marketing methods. Steel is produced against a tangible demand, as shown by accumulated orders. A constant effort is made to relate output to sales. The output is not seasonal except as demand is seasonal; the total supply does not come on the market in three or four months (as in the case of farm products). There is no need of a central market equipped with storage facilities to carry a surplus supply. Frequent handlings of steel would be costly and would serve no economic end. The markets are located, logically and inevitably, at the mill offices, and, in a secondary sense, at jobbers' warehouses.

Not infrequently conditions develop which are favorable to speculation in steel products. Thus in 1921-22 which was a period of declining prices, various large manufacturing consumers proceeded to sell out their stocks of steel bars, plates, and structural shapes. In some instances the consumer was led to sell his stocks by unfavorable conditions in his own business; in other cases selling was undoubtedly done with a view to replacing his stocks at lower prices. This, of course, added to selling pressure on the supply side of the

[1] Two attempts have been made to develop a market for pig iron warrants (future contracts) in the United States, the last one about ten years ago.

market, accelerated the price decline, and also accelerated the subsequent upswing of prices. Hence it strengthened the opposition to speculation in steel products.

It is well recognized that the United States Steel Corporation and the three or four large independents make every effort to prevent violent fluctuations in price. Their customers are led to expect that prices will not be moved up rapidly by the larger producers in times of high activity; and, on the other hand, they do not expect price-cutting or underbidding to any marked extent when business becomes less active. This is made possible by the fact that every large steel company does a considerable part of its business with "regular customers" and price-cutting need not be resorted to as a means of getting trade. The railroads, for example, follow the regular practice of apportioning their orders among the companies who give them the most traffic.

Pricing: Pittsburgh-Plus

Because of the desire for stability of price and the persistent opposition to speculation in rolled steel, the problem of pricing has been of foremost importance. In fact, the pricing problem, as developed in the controversy over "Pittsburgh-plus," has received more attention from the general public than almost any other phase of the industry.

The device of selling on a Pittsburgh base price

originated out of the early predominance of Pittsburgh as a central market for steel and was closely associated with the growth of the Steel Corporation. It was to be expected that the Steel Corporation, as a means of controlling its own production, would sell the products of all mills on the basis of values established at a central point—*i.e.*, Pittsburgh. An organization of this size would scarcely be expected to sell at a uniform delivered price. Such a practice would have implied the necessity of "meeting competition" as a means of obtaining business.

It was a different matter, however, for *Pittsburgh plus freight* to be adopted as a method of pricing for the entire industry. This meant that the price of rolled steel would be the same at any consuming point regardless of where or by whom the metal was produced and regardless of the point from which it was shipped. For rolling mills outside of the Pittsburgh district it meant selling at a delivered price on the basis of a central shipping point—*i.e.*, Pittsburgh. Thus an independent producer at Chicago would bill steel sheets at a price consisting of the "Pittsburgh base" plus the all-rail freight rate from Pittsburgh, the purchaser to deduct from the invoice the amount of transportation actually paid, remitting the balance to the mill.

This became the customary practice in relation to many products. Quotations of prices on steel were ordinarily made f. o. b. Pittsburgh. This was the standard form of quotation. The freight rate from

Pittsburgh to the point of delivery was customarily added to this base to make the delivered price. Thus a fabricator buying steel at Chicago had to pay as much as if he bought the steel at Pittsburgh, while a Pittsburgh fabricator, buying steel at Pittsburgh, had to pay only the Pittsburgh price. Here was the main contention in the attack upon the Pittsburgh-plus system: That the independent fabricator and his customers lost the advantage of a strategic location and seemed to be paying a fictitious price made up of the cost at Pittsburgh plus an assumed freight charge from Pittsburgh, rather than the actual cost of steel at the point produced plus the freight actually paid.

It was argued by the Steel Corporation that such a practice had a sound economic basis in the fact that Pittsburgh was the point of surplus production; that fabricators, wherever located, would, in any case, have to buy some steel from Pittsburgh; and that it made for stability in the industry to charge the Pittsburgh-plus price.

And this argument was not without economic justification. Wherever the potential supply of a nonperishable commodity in a given area is inadequate to the local consumers' needs, the price will tend to be governed by the cost of delivering the goods from some outside area. This is the so-called marginal theory of price. It means that the price obtainable for a supply which is inadequate to local needs will be no greater (so long as the transportation system functions) than that

paid for goods brought in to meet the deficiency. And, conversely, the price obtainable by shipping goods to other markets, in the case of an excess of production, will tend to govern the price obtainable in the local market.

The direct application of this principle to the pricing of steel will appear in the paragraphs below.

Under the Pittsburgh-plus system the delivered price was always known to every important user of steel. One of the subsidiaries of the Steel Corporation published a freight-rate book giving the actual freight rates from Pittsburgh to all consuming points in the United States. The Steel Corporation had merely to announce its Pittsburgh price and the delivered prices were immediately known to every factor in the trade, purchasers and competitors alike.

The practice was not applied, however, to all products or to all consumers. Because of a concerted protest from Southern consumers of steel the Pittsburgh-plus system had been abandoned for Birmingham mills in 1908 with respect to plates, shapes, and bars. A Birmingham base price was established at a fixed differential over the Pittsburgh price. Moreover, the practice was eliminated at Chicago in 1921, so far as it applied to plates, shapes, and bars. These products were marketed by the Chicago mills on a Chicago base price. Then, also, the railroads were exempt from the practice, being given a mill price at all steel mills. The railroads could not be expected to pay a price including

freight, since they could take delivery at any point on their rails.

With respect to other products and other consumers, the Pittsburgh-plus method was regularly applied and was in effect practically from 1901 until 1924, when it was forbidden by order of the Federal Trade Commission. The Steel Corporation was then ordered to cease and desist from selling or quoting for sale rolled-steel products (in interstate commerce) upon any basing point other than that where the products were manufactured or from which they were shipped. This decision was accepted without further protest.

The case had turned on an economic argument to the effect that under the Pittsburgh-plus system an open competitive market, in the full sense of the term, did not exist. The opponents of the system argued that such a price did not represent an adjustment between supply and demand, in the strict use of the term, except in the case of buyers dealing with Pittsburgh producers. There was not, for example, a Chicago price resulting from the adjustment of supply to demand at the Chicago market; but on the contrary steel products were shipped from Chicago at delivered prices determined by conditions at Pittsburgh, the buyer paying the actual freight. Thus, they said, instead of open competitive markets at the various steel centers there was (to the extent that Pittsburgh-plus was applied) only the one central competitive market at Pittsburgh.

It is as yet too early to determine whether the aboli-

tion of this practice has resulted in the establishment of open competitive markets at all important producing centers. Yet certain results are already apparent.

Pricing: Plural Basings

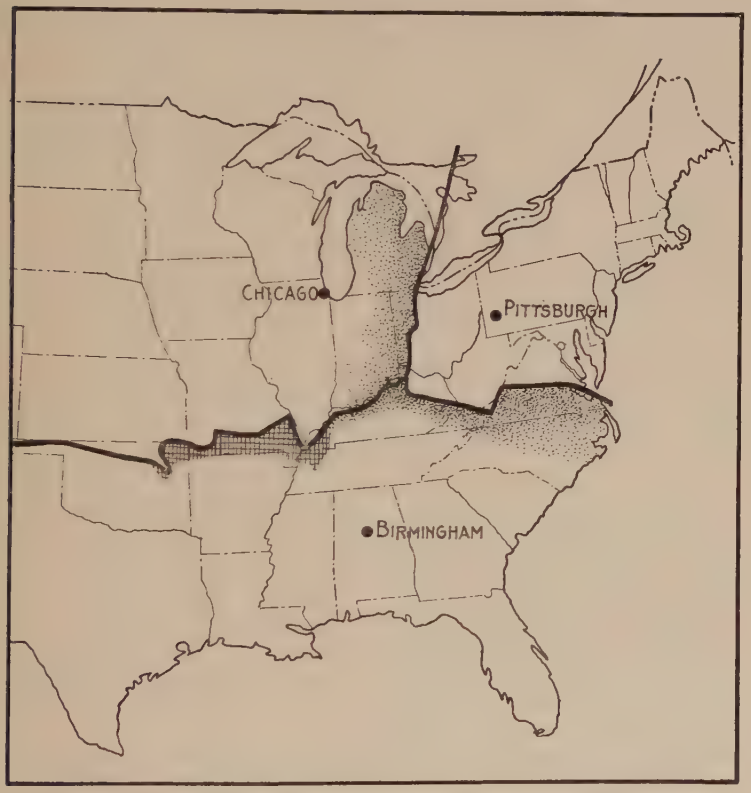
The Federal Trade Commission sought to eliminate the practice of meeting competition at delivery points by prescribing a system of f. o. b. mill prices, with freight to destination shown as a separate figure. The commission's decree, however, was directed solely against the Steel Corporation, and the independent companies were under no obligation to follow it.

Outside steel centers had been gaining on Pittsburgh in steel capacity for about twenty years. Some of the independent companies had located and expanded their plants with Pittsburgh-plus as an important factor in their calculations. They had counted on the excess of freight from Pittsburgh over actual freight costs from their mills to offset any unfavorable differences in manufacturing costs. This was especially true of Eastern mills.

For "Pittsburgh-plus" was more than a convenient method of pricing; it was for years "the keystone of the organization, location, and alignment of the American steel industry."[1] In practice it not only assisted the Steel Corporation to intrench itself in growing markets outside the Pittsburgh district; it also assisted the smaller independents in competing with the Steel Cor-

[1] A. O. Backert in *Iron Trade Review*, January 1, 1925.

poration, especially in the Middle West. The independent companies were reluctant to give up Pittsburgh-plus and in many instances they have continued this form of pricing or something akin to it.



DIVISION OF COMPETITIVE TERRITORY AMONG THREE STEEL CENTERS
(*Permission of Iron Trade Review*)

The gist of the matter is that the scheme of plural basings is a handicap to companies poorly located with reference to their customers, and operates to stim-

ulate production at centers close to the growing markets. On the basis of population trends and industrial development there is every incentive to build up the industry in the Chicago territory. A line drawn west of Lake Erie and passing just east of Toledo, through Dayton and just west of Cincinnati, divides the country into Chicago and Pittsburgh territories. Steel development west of this line will be stimulated by the abolition of Pittsburgh-plus because there is every incentive to bring capacity up to consumptive requirements in the Chicago territory.

The Chicago region has been from 2,000,000 to 3,000,000 tons short of finished steel to meet its normal annual requirements. Until this gap between production and consumption is closed up consumers in the Chicago area must frequently go some distance outside their district and pay higher prices for steel. Under Pittsburgh-plus this made less difference; with Pittsburgh-plus eliminated it constitutes an incentive to greater development in the Chicago district.

With Pittsburgh-plus eliminated, freight-rate advantage became the outstanding factor in marketing steel. It became apparent that the domestic market would divide itself into Pittsburgh, Chicago, and Birmingham territories.

This does not mean that these three producing centers control the business today, since under the new methods of pricing several basing points have developed for each of the more important products. Wire

products are quoted on Pittsburgh, Cleveland, Chicago, Worcester (Mass.), Birmingham, Duluth and Anderson (Ind.). Prices of wrought-iron pipe are based on Pittsburgh-Wheeling and Loraine, Ohio. Cleveland has become the basing point for semi-finished steel, wire rods, and cold rolled strip steel. In the bolt and nut industry basing points have been eliminated and a zone system adopted, full freight being allowed to destination within the zone. (Such a plan had been followed previously in the industry, prior to the general adoption of Pittsburgh-plus.) In brief, although there has been no drastic redistribution of business, markets tend to become more definitely localized.

With many basing points in operation, transportation costs are a primary factor in defining market areas. In some instances shippers are using water freight, shipping by barge and ocean vessel, to overcome rail freight disadvantages in important markets. In many cases, rather than incur the cost of building up new trade they are absorbing part or all of the freight charges on shipments to long-established customers.[1]

It is of interest to note that through the existing relationship between transcontinental and water rates the Pacific-coast market is largely lost to the Chicago market and is held by mills which can ship to advantage through the Panama Canal (notably the Birmingham mills).

In fact, water transportation is being used to deliver

[1] See *The Iron Age*, January 7, 1926.

steel as never before. The rehabilitation of the Ohio River as an inland waterway is enabling Pittsburgh district producers to reach not only the Ohio River cities, but Memphis, Vicksburg, and New Orleans on a competitive basis. Moreover, steel is moving to the Gulf ports by ocean vessel from the Atlantic seaboard (or Europe) and by rail and water from Birmingham. At present Chicago can participate in the Mississippi River traffic only through shipping to Cairo or St. Louis by rail and transferring to river barges. Plans are under way, however, for the development of an all-water route to the Gulf.

Plural basings also give a new importance to plant costs. A freight-rate advantage may, of course, be offset by higher costs of production. As an example, it was once figured that a ton of steel required 2½ tons of coal. That is, 1½ tons of coal was used for each ton of coke used to make a ton of pig iron, and another ton was used in gas producers and under boilers. Now it is reported that steel companies having by-product coke plants, by a proper grouping of coke ovens, blast furnaces, steel works, and rolling mills, can figure their coal requirements at 1½ tons of coal per ton of steel. Where coal is cheap, as at Pittsburgh, this makes possible a lower base price on certain products.

In brief, Pittsburgh prices still furnish the basis for comparison, but they are by no means strictly followed. On many products the differential over Pitts-

burgh is considerably less than the freight-rate advantage, and on some products steel has been sold at other centers at prices even with Pittsburgh. In fact, in the case of plates, the Eastern mills have quoted from $1 to $2 a ton under Pittsburgh mill prices. This is probably due to the large plate-making capacity in the East.

The price situation today is shown by the efforts of the Steel Corporation to name differentials at its several points of plant location, which would make it difficult for some of the independents to compete:

> It was thought that in naming prices for sheets and tin plate at $2 a ton over Pittsburgh at Gary, wire products at $2 over Pittsburgh at Chicago district mills, $3 over Pittsburgh at Worcester, Mass., and Birmingham, and $4 over Pittsburgh at Duluth and $2 a ton over Pittsburgh at Gary and $3 over Pittsburgh at Birmingham for plates, shapes, and bars, the Corporation was cutting the cloth rather tight for the independents, and that these differentials, in all cases much less than the freight from Pittsburgh to those points, would leave the independent companies on the outside until the Corporation subsidiaries had become filled up. It did not work out that way, because the independents were not to be deprived of the reward of years of effort in building consuming connections. In wire products, the differentials have been reduced except at Worcester and Birmingham. Duluth now has prices only $2 a ton over Pittsburgh on wire products, while the differential over Pittsburgh at Chicago—and this means Chicago delivery as well as mill prices—is only $1 a ton except on woven-wire fence.[1]

Multiple basing also places certain consumers in a position of advantage. The fabricator of steel located

[1] *The Iron Age*, January 7, 1926, p. 38.

50 miles from mill A and 1,000 miles from mill B will get from both mills delivered prices based on the 50-mile haul. Yet a fabricator located 200 miles from mill A and 800 miles from mill B will have to pay a considerably higher price. Thus it developed in 1925 that Lynn, Mass., was buying steel 11.5 cents per 100 lbs. cheaper than Bridgeport, Conn., even though steel shipped to Lynn from Pittsburgh passed through Bridgeport. The reason was that Pittsburgh had to meet competition from Worcester, Mass., and the delivered prices varied with the freight rate, not from Pittsburgh, but from Worcester.

Thus the entire process of marketing steel, so far as marketing is governed by price competition, is now in a state of flux. Plant location is now a factor to be reckoned with quite as much as manufacturing costs. Yet there is still a strong incentive to regard the Pittsburgh base price as a guide to quotations throughout the industry. It should be borne in mind that Pittsburgh is still the most important steel center in the United States and that shipments from Pittsburgh are necessarily sold on the Pittsburgh base. Moreover, the position of the Steel Corporation is quite as strong under the rule of plural basings as it ever was under Pittsburgh-plus.

CHAPTER XIX

Financing the Steel Industry[1]

A modern steel plant is conspicuous because of its gigantic plant facilities. From the very nature of the products and the processes required in their creation a large proportion of the total investment must consist of fixed capital. This large proportion of fixed capital and the correspondingly large proportion of fixed charges is a major factor in the problem of financing the industry.

For this reason the problem of financing a steel company is more akin to that of a railroad or public utility than to that of most other manufacturing concerns. To be sure, steel making is not subject to public regulation and the prices of steel products are determined in the open market. But the ratio of sales to fixed property investment (the turnover of fixed capital) is bound to be low and the problem of fixed charges takes a prominent place in financial policy. In comparison, manufacturers of automobiles and trucks may turn their fixed assets three times; in the meat-packing industry a common ratio of sales to fixed assets would be about 10 to 1; but for iron and steel makers a ratio of .7 to 1 would represent the average performance.

[1] By Edmund Brown, Jr.

That is, year in and year out, the steel industry will require considerably more dollars invested in fixed capital than it takes in from annual sales.[1]

An analysis of the statements of various groups of industrial concerns for the eight-year period 1914-1921 disclosed these figures:

Industry	*Number of years covered*	*Number of companies*	*$ of sales per $1 of fixed property investment*
Slaughtering and meat-pkg..	9	4	$9.62
Auto-accessory mfg.....	5	6	4.77
Electrical machinery mfg....	8	3	4.55
Auto and truck mfg.....	6	5	2.95
Cotton-goods mfg.....	7	4	2.70
Machinery mfg.....	6	4	2.32
Railway-equipment mfg.....	8	4	1.43
Sugar producing and refining	8	4	1.11
Paper mfg.....	5	2	1.01
Lead production and mfg....	7	2	.75
Iron and steel mfg.....	8	6	.70

Some of the smaller companies, specializing in a restricted line of finished steel, show results well above this average. The Atlantic Steel Co., for example, has reported in recent years gross receipts amounting to about one and one-half times the value of plant and equipment as carried on its books.

The steel industry is thus at the bottom of the list in respect to the turnover of fixed capital; and with all

[1] See Bliss, J. H., *Financial and Operating Ratios in Management*, 1924 p. 152.

the improvement in technique, plant productivity is still relatively low.

Viewing the problem from another angle, it appears that over 70 per cent of the total capital employed in the iron and steel industry consists of fixed assets. For the year 1921 the fixed assets of eleven steel companies represented 72.4 per cent of their total capital, while of the total capital employed by eleven automobile and truck manufacturers the fixed property investment accounted for only 40.6 per cent.[1]

This large fixed capital requirement has several results. The more important are these: (1) the tendency toward consolidation and integration, with a view to reducing overhead costs and making the plant facilities more productive; (2) a concerted effort to stabilize prices, so as to insure an ample margin of income over and above obligatory charges; (3) a conservative dividend policy, because of the inability to prevent fluctuations in profits and, also, because of the desire to expand the business out of earnings.

The second of these factors—the effort to stabilize prices—was discussed in the preceding chapter.

Integration and Consolidation.—During the decade which preceded the formation of the Steel Corporation there developed a vertical and lateral process of combination in the steel industry: first, by putting together, or "integrating," the successive stages of production from iron mine to rolling mill; and, second, by

[1] *Ibid.*, p. 165.

consolidating companies which made the same finished products.

The first movement found its justification in certain operating economies. Materials could be handled more economically; there was a saving of heat in transferring the molten iron from the blast furnace to the steel works. And the gases from coke plants and blast furnaces could be efficiently utilized as a source of power or fuel. It also eliminated delays and embarrassments in obtaining materials when needed in times of active production, together with the added cost due to the bidding up of the prices of materials under such conditions of unusual demand.

The second movement—that of lateral combinations—was usually justified on the ground that each mill or plant would be allowed to specialize in certain products and so could effect economies in production.

The formation of the United States Steel Corporation in 1901 carried forward these movements of integration and combination and set up an establishment which then embraced 60 per cent of the steel industry. It brought together several of the most powerful integrated companies and also the chief combinations of manufacturers which had formerly competed in the sale of finished products—such as wire, tubes, sheets, and tin plate. It acquired, then and subsequently, large holdings in the Lake Superior ore properties. It obtained extensive deposits of high-grade coking coal in the Connellsville and the West Virginia regions. It

got possession of several railroads especially adapted to the transportation of iron. Then, in later years, other large steel companies were brought in, the most important being the Tennessee Coal, Iron & Railroad Co., which dominated the southern district. Thus the Steel Corporation has become a thoroughly integrated concern; many of its mills are highly specialized; and its plants are strategically located with reference to the consuming areas.

Today the Steel Corporation controls about 40 per cent of the country's capacity for steel production. The Bethlehem Steel Corporation (which purchased in 1922 the Lackawanna Steel Co., and in 1923 Midvale Steel and Ordnance Co. and Cambria Steel Co.) has about 14 per cent. Jones & Laughlin has about 5 per cent, Youngstown Sheet & Tube Co. about 5 per cent, and Republic about 2½ per cent. These four independents, therefore, control about 26 per cent, leaving a balance of 34 per cent distributed among a number of large, medium, and small companies.

Costs and Profits.—Viewing these groups as a whole, it is safe to assume that the large, highly integrated companies (controlling the successive stages of production) have, as a rule, lower costs of production than the smaller concerns which combine only one or two stages of the business and buy their materials in the open market.[1] It is a striking fact, however, that the low

[1] See Federal Trade Commission, *War-Time Profits and Costs of the Steel Industry*, 1925.

costs of production achieved by the highly integrated companies do not invariably result in higher rates of profit on the invested capital. In fact, it appears that the larger companies, especially in years of heavy production, show a lower rate of return on investment (capital stock, bonds, and surplus) than most of the smaller companies. This is sometimes said to be due to excessive capitalization in organizing a large holding company. While this may have been true years ago it is hardly the case today. A more probable reason lies in the fact that in times of unusual demand—as in the war period—the smaller company is inclined to solicit the most lucrative business obtainable while the larger concern is more apt to follow a policy of taking care of its regular customers year after year.

TABLE 1.—*Reported investment and earnings of steel companies, excluding the Steel Corporation, grouped according to extent of integration, 1915–1918*[1]

Year and class	Number of companies	Investment [1]	Earnings	Rate of return
1915–1918				
Class I	14	$3,300,927,533	$724,118,513	21.9
Class II	10	563,570,554	137,804,916	24.5
Class III	25	261,932,017	94,871,253	36.2
Class IV	42	304,133,802	112,005,675	36.8
Average		1,107,625,977	267,200,089	24.1

[1] Class I comprises companies producing a large part of the ore and coke they use; Class II, companies beginning with the making of pig iron; Class III, companies beginning with the making of steel; Class IV, companies operating rolling and finishing mills only. Earnings are taken before deduction of bond interest or Federal income and excess profits taxes.

The increased earnings of the smaller companies were shown in a study made by the Federal Trade Commission of the war-time profits of the industry, covering the four years 1915-1918. This was, of course, a period of maximum production and of abnormally high profits. The results obtained by all companies, excluding the Steel Corporation, appear in Table 1.

The rates of return shown by the Steel Corporation on an average investment in those years of about two billion dollars are shown below:

TABLE 2.—*Investment and earnings of the Steel Corporation, as compiled from its annual reports, 1915–1918*

Year	Investment	Earnings	Rate of return
1915	[1] $1,902,362,632	$128,361,908	6.7
1916	1,948,556,199	361,407,845	18.5
1917	2,185,314,633	537,913,163	24.6
1918	2,325,119,852	492,567,309	21.2
Average	2,090,338,329	380,062,556	18.2

[1] Investment for 1915 obtained from balance sheet at end of 1914. Earnings are taken before the deduction of bond interest or of Federal income and excess profits taxes.

The above figures represent earnings prior to the payment of federal taxes, which at this time were very heavy. In 1918, for example, more than 40 per cent of the net earnings of the independents were paid out as income taxes and more than 50 per cent of the Steel Corporation's earnings were so distributed.

Earnings on Proprietary Capital.—From the stockholders' standpoint it will be more useful to examine the earnings actually available for dividends on the common stock and to show these earnings in relation to the total proprietary capital (common stockholders' investment). Furthermore, if the figures are to be set up as typical for the industry they should apply to a period of more nearly normal production.

Table 3 shows for eleven steel companies during the years 1921-1925 the net assets per share of stocks outstanding (at the beginning of each year), the earnings per share, and the percentage earned on the equity or common stockholders' investment.

An analysis of this sort is important because it might well be assumed that those who have a proprietary interest in the business would receive a rate of return on their total investment comparable to the rate paid to outside investors. The fact that they see fit to leave part of their earnings in the business to be employed for capital expansion and for various reserves does not alter the fact that this is part of their investment. Numerous instances might be cited of industrial corporations which have expanded out of earnings and have, from time to time, turned back their surplus accumulations in cash or new stock to the original stockholders.

This cannot be said of the steel companies. Stock dividends have been comparatively infrequent. The steel companies have expanded, for the most part with-

TABLE 3 —*Net assets and earnings per share of common stock and percentage earned on proprietary capital (common stockholders' equity) for eleven steel companies during the years 1920–1925*

	1925			1924			1923		
	Net assets per sh. common	Earnings per sh. common	% Earned on com. stockholders' equity	Net assets per sh. common	Earnings per sh. common	% Earned on com. stockholders' equity	Net assets per sh. common	Earnings per sh. common	% Earned on com. stockholders' equity
U. S. Steel Corporation	$272.94	$12.86	4.7	$267.94	$11.77	4.4	$257.08	$16.42	6.4
Bethlehem Steel Corp	156.82	5.30	3.4	174.32	2.57	1.6	237.32	6.47	2.7
Jones & Laughlin Steel Corp	186.48	10.39	5.6	176.00	8.21	4.5	167.00	12.27	7.3
Youngstown Sheet & Tube Co.	102.23	12.00	11.8	104.00	6.68	6.4	103	14.93	14.5
U. S. Cast Iron Pipe & Foundry Co	194.02	38.84	20.0	150.72	43.17	28.6	129.84	21.93	16.9
(b) Crucible Steel Co. of America	142.38	5.05	3.5	141.84	4.55	3.2	140.01	5.20	3.7
Republic Iron & Steel Co	213.79	6.88	2.5	213.61	0.55	.....	198.78	15.01	7.5
(c) Pittsburgh Steel Co	148.74	1.82	1.3	154.24	4.82	.....	149.04	8.38	5.6
Sloss-Sheffield Steel & Iron Co.	193.50	14.50	7.5	188.93	10.47	5.5	168.28	20.22	12.0
Colorado Fuel & Iron Co	104.03	4.65	4.5	103.40	1.05	0.3	101.78	1.67	1.6
Virginia Iron, Coal & Coke Co	102.75	0.68	.7	106.29	Deficit	.....	107.72	2.07	1.9

(a) On common and common "B" stocks.
(b) Fiscal year ending August 31.
(c) Fiscal year ending June 30.

TABLE 3.—*Continued*

	1922			1921			1920		
	Net assets per sh. common	Earnings per sh. common	% Earned on com. stock-holders' equity	Net assets per sh. common	Earnings per sh. common	% Earned on com. stock-holders' equity	Net assets per sh. common	Earnings per sh. common	% Earned on com. stock-holders' equity
U. S. Steel Corporation	$259.46	$ 2.84	1.1	$260.42	$ 2.24	.9	$244.76	$16.62	6.8
Bethlehem Steel Corp	252.97	(a) 1.44	.6	247.00	11.51	4.7	231.07	18.40	7.9
Jones & Laughlin Steel Corp.	155.29	2.44	15.7	.....	.....	.....	.....	.....	.....
Youngstown Sheet & Tube Co.	86.27	3.76	4.4	85.87	Deficit	.....	.....	.....	.....
U. S. Cast Iron Pipe & Foundry Co.	126.22	1.52	1.2	130.31	Deficit	.....	128.11	0.09	.1
(b) Crucible Steel Co. of America	154.29	Deficit	.....	164.12	7.59	4.6	.....	20.41	.....
Republic Iron & Steel Co.	203.30	Deficit	.....	232.45	Deficit	.....	232.49	19.55	8.4
(c) Pittsburgh Steel Co.	152.13	Deficit	.....	302.16	7.87	4.6	292.64	22.37	7.6
Sloss-Sheffield Steel & Iron Co.	162.06	1.10	.7	178.71	0.45	.3	169.93	20.38	12.0
Colorado Fuel & Iron Co.	104.10	Deficit	.....	114.12	Deficit	.....	114.71	3.29	2.9
Virginia Iron, Coal & Coke Co.	104.35	3.26	3.1	115.01	3.35	2.9	109.14	21.40	19.6

out increasing their capital stocks (except in the case of mergers). This has in most cases increased the book value per share of capital stock. But it has not been a source of large earnings per share to the stockholders. The Steel Corporation, for example, has more than doubled its net worth since incorporation, and this has been done almost entirely out of earnings. Yet in 1925, which was an unusually good year, the corporation earned only $12.86 per share on stock having a book value of $272.94. This amounts to a return of about 4.7 per cent on the proprietary capital. In 1921, which was a year of depression, the return on proprietary capital was only .9 of one per cent! The reason for not declaring stock dividends is perfectly obvious: there is not sufficient earning power to pay an adequate return on an increase in the outstanding shares.

The Pittsburgh Steel Company is an exception to this statement of general policy since it has twice declared substantial stock dividends—100 per cent in 1920 and 25 per cent in 1923. This company had no funded debt and to increase the capitalization in conformity with an increase in surplus would not seem to have been a reckless financial policy. It is a notable fact, however, that the Pittsburgh Steel Company has had to draw upon surplus to pay common dividends in three of the past four years, and has been unable to build up its surplus account to any considerable extent since 1920.

The following conclusions may be reached:

1. While the Steel Corporation, as the dominant factor in the industry, has shown steadiness of earning power, this earning power as related to invested capital has not been high. In fact, the rate of return on proprietary capital has been lower in recent years than the dividend rate. A dividend disbursement of 7 per cent in 1925 was warranted because of the large equity ($273) per share of common; the earnings per $100 of proprietary capital amounted to about $4.70.

2. Certain independent companies show a higher rate of return on total invested capital and so are in a position to pay relatively heavier fixed charges and preferred stock dividends. The notable examples are Youngstown Sheet and Tube Co., U. S. Cast Iron Pipe & Foundry (in recent years), and Sloss-Sheffield Steel & Iron Co.

3. Generally speaking, the average return on total invested capital has been low (excepting the war period) and it has been necessary for most companies in recent years to build up their properties out of earnings. Failure or inability to do this has made it impossible for the weaker companies to maintain anything like a regular rate of dividends on the common stock.

These conclusions become clearer when a comparison is made on the basis of rate of return on total capital employed. Compare, for example, the operations of the Steel Corporation with those of Sloss-Sheffield, one of the stronger independents, in the year 1924.

1924	U. S. Steel Corporation	Sloss-Sheffield Steel & Iron Co.
Total assets (average)	$2,419,500,000	$34,077,000
Net operating profit	128,097,711	2,807,953
Ratio of net to total assets	5.3%	8.2%
Interest and preferred dividends times earned	2.37	2.28
Per cent earned on common	11.77%	10.47%
Per cent earned on proprietary capital	4.4%	5.5%

The figures show that Sloss-Sheffield had a yield of 8.2 per cent on the average fund of capital, while the Steel Corporation had a yield of only 5.3 per cent. Yet Sloss-Sheffield operated on a larger proportion of borrowed capital and so reported only 10.47 per cent earned per share of common, against 11.77 per cent for the Steel Corporation.

Expansion Out of Earnings

The policy of expansion out of earnings appears nowhere with greater force than in the record of the Steel Corporation. In the twenty-five years of its existence this concern has turned back over 41 per cent of its net income into the business. The figures are as follows:

(April 1, 1901, to Dec. 31, 1925)

Balance of profits available for dividends	$2,185,712,403
Dividends paid on preferred and common stocks	1,279,253,785
Earnings left in business	$ 906,458,618
Appropriated for capital expenditures and special charges	409,595,509
Capital surplus at date of organization	25,000,000
Total surplus, December 31, 1924	$ 521,863,109

The Steel Corporation itself never has obtained outside capital as a means of financing capital improvements. The entire program of capital development, subsequent to its formation in 1901, has been financed out of earnings. It has already been shown, however, that the Steel Corporation started with a sufficiently heavy burden of borrowed capital. It was only a matter of conservative policy to build up its reserves and surplus account.

A more detailed analysis of the proportions of earnings left in the business, as reported by the leading companies, appears in Table 4.

This analysis shows that eleven steel companies during the six-year period 1920-1925 earned a net income of $690,627,000. Of this amount $470,918,000 was disbursed to preferred and common stockholders as dividends. The balance, or 32 per cent of the net income, was left in the business. This was not a mere policy of conservatism; it was a means of financing the growth of the business—of procuring capital without increasing

TABLE 4—*Net income, dividends, and percentage of net income left*

	1920–1925			1925			1924		
	Earned	Dividends	% left in bus	Earned	Dividends	% left in bus	Earned	Dividends	% left in bus
U. S. Steel Corp.	$470,341	$327,954	31	$90,603	$60,801	34	$ 85,067	$60,801	34
Bethlehem Steel Corp.	66,545	46,067	30	13,858	4,303	69	8,916	9,869	10 [1]
Republic Iron & Steel Co.	14,736	12,750	36	3,813	1,750	54	1,918	2,000	04 [1]
Crucible Steel Co. of Amer. (years ended August 31)	27,180	22,948	30	4,525	3,950	13	4,250	3,950	07
Sloss-Sheffield Steel & Iron Co.	9,586	4,295	55	1,979	1,069	46	1,516	1,069	29
Pittsburgh Steel Co. (years ended June 30)	8,821	8,434	13	1,053	1,435	27 [1]	1,511	1,539	02 [1]
U. S. Cast Iron Pipe and Foundry Co.	16,968	5,041	70	5,501	1,441	74	6,021	960	84
Colorado Fuel & Iron Co.	908	2,500	28	1,752	160	91	520	160	69
Youngstown Sheet & Tube Co.	47,518	27,087	36	13,228	4,947	62	7,598	5,441	28
Jones & Laughlin Steel Corp.	[2] 29,494	[2] 11,795	60	9,954	3,993	60	8,626	3,922	54
Virginia Iron Coal & Coke Co.	3,700	2,047	35	193	125	35	d 54	250	100 [1]
Totals	$690,627	$470,918	32	$146,459	$83,974	...	$125,889	$89,961	28

[1] Percentage of dividends paid out of surplus.

[2] Three years only.

in the business, for 311 steel companies, 1920-1925 (000 omitted)

1923			1922			1921			1920		
Earned	Dividends	% left in bus	Earned	Dividends	% left in bus.	Earned	Dividends	% left in bus.	Earned	Dividends	% left in bus
$108,707	$54,447	50	$39,653	$50,635	22 [1]	$36,617	$50,635	28 [1]	$109,694	$50,635	54
14,374	12,086	16	4,605	6,937	34 [1]	10,333	6,436	38	14,459	6,436	55
6,252	3,250	48	418	.....	100	d 5,282	2,200	100 [1]	7,617	3,550	53
4,611	2,299	50	d 3,710	2,749	100 [1]	5,547	5,250	5	11,957	4,750	60
2,491	469	81	579	.....	100	514	619	17 [1]	2,507	1,069	51
1,908	1,295	32	211	1,295	83 [1]	1,837	1,575	14	2,301	1,295	44
3,471	840	76	1,022	600	41	101	600	83 [1]	852	600	30
732	160	78	d 654	160	100 [1]	d 2,731	673	100 [1]	1,287	1,187	7.8
11,335	5,613	51	3,707	2,894	22	d 167	2,694	100 [1]	6,703	5,498	18
10,914	3,880	64	.....	.....	.....	.....	.....	.....	.....	.....	...
457	250	55	575	250	57	335	600	44 [1]	2,140	572	...
$165,252	$84,589	49	$16,406	$65,520	29 [1]	$47,104	$71,282	34 [1]	$159,517	$75,592	53

the yearly fixed charges. The wisdom of such a policy has been shown in the low earnings realized on proprietary capital during the years of depression.

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